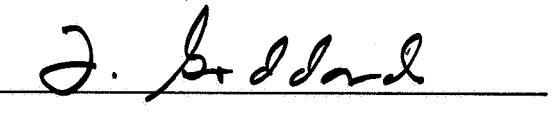
701-185

ANNUAL REVIEW OF
RESEARCH AND ADVANCED DEVELOPMENT
JULY 1, 1972 – JUNE 30, 1973

August 15, 1973

Supporting Research and Technology
for the Office of Space Science and the Office of Applications,
National Aeronautics and Space Administration

Approved By: 

F.E. Goddard, Jr.
Assistant Laboratory Director
for Research and Advanced
Development

INTRODUCTION

This document contains a report on Research and Advanced Development progress at the Jet Propulsion Laboratory during the period July 1, 1972, to June 30, 1973, sponsored by the NASA Office of Space Science and the NASA Office of Applications.

Reports on ongoing Research and Technology Operating Plans (RTOPs) are arranged in numerical sequence by NASA Code. To locate a desired RTOP, refer to the Table of Contents.

Formal publications resulting from the conduct of the work are listed, where appropriate, at the conclusion of each RTOP report.

CONTENTS

CONTENTS (contd)

COMMUNICATIONS SYSTEMS ANALYSIS
NASA RTOP 164-06-50

J.C. Springett

OBJECTIVE

The general emphasis of the RTOP has been regarding bandwidth reduction techniques for the purpose of alleviating overcrowding of frequency band allocations. Two distinct efforts were the subject of the FY'73 research:

(1) A detailed assessment of the terrestrial link applications for bandwidth-efficient digital modulation techniques, and

(2) A rigorous analysis of the entire family of simultaneous phase and amplitude modulation formats, and the selection of one efficient and cost-effective approach for system synthesis and performance testing.

PROGRESS

Good progress was made in all areas.

Data-Aided Receiver Technical Report

A JPL Technical Report (TR 32-1583), describing nearly 3 years of research conducted on the development of the data-aided suppressed carrier receiver will be distributed this summer. The report, more than 100 printed pages, contains the complete system motivation, theory, implementation, and application of the digital-data suppressed carrier receiver. The data-aided receiver concept forms the underlying discipline for implementing more complex receivers required for the reception of simultaneous phase and amplitude modulated signals. TR 32-1583 is therefore a primer for the understanding of present and future progress on bandwidth conserving signaling systems.

of effort due to the demise of the NASA communication satellite program.

Terrestrial Link Applications for Bandwidth-Efficient Digital Modulation Techniques

Many terrestrial communication environments suffer from spectrum congestion, and offer potential application areas for bandwidth-efficient digital techniques. Consideration has been made of the nature and extent of the congestion in the 4-, 6-, and 11-GHz common carrier microwave bands, the 12-GHz Community Antenna Radio Station (CARS) microwave band and wire and cable systems including telephone lines, two-way cable television with upstream digital capability, and dedicated digital common carriers. All links that were studied were considered strictly from the spectrum congestion perspective since bandwidth-efficiency was the sole motivation for the modulation forms considered.

Since the multiple phase shift keying (MPSK) and quadrature amplitude shift keying (QASK) forms of modulation represent the general classes of digital modulation, and trade power and complexity to save or conserve bandwidth (or to expand the data rate), only their application was considered on spectrum congested links. Further, these forms of modulation can be expected to be bandwidth-efficient only in media which can be adequately characterized as essentially linear. Examples of terrestrial links which purportedly satisfy this criteria include microwave links (particularly in the 4- and 6-GHz common carrier bands and the 12-GHz CARS band), cable, and wire systems. Application studies were constrained to consider only those where the existing or anticipated form of modulation is digital, or where conversion of analog-to-digital form would be beneficial.

Examination of the several terrestrial areas of application for bandwidth reducing M-ary techniques indicated only limited potential in all but a few isolated circumstances. Some specific conclusions reached are:

(1) Cable antenna TV's (CATV's) attempts to provide a digital upstream capability will probably be dominated by interference problems, and eventually resolved at the expense of spectrum, or with multiple cable systems.

(2) Cable or wire systems dedicated to carrying information of an inherently digital nature offer a potential application for M-ary communication. Connections between public institutions, business, and industrial centers will probably involve transmission of digital data at rates in excess of the telephone line (binary) capacity, especially for computer linking. Sophisticated digital techniques might be used to permit use of wire rather then cable.

(3) The conversion of present analog links to handle bandwidth-efficient digital signals appears to be inefficient and cost ineffective.

(4) Most terrestrial microwave links are analog transmission systems utilizing single channels or multiple channels with frequency division multiplex. Time division multiplexed digital systems are rare, with DATRAN, the specialized digital common carrier, the most notable exception. Due to the opening of higher frequency bands for microwave (this minimizes present problems), the potential application of any sophisticated form of digital modulation in this area appears limited.

In conclusion, there are no clear cut applications of bandwidth conserving modulation in the microwave regions, but there probably are applications in cable or wire systems, particularly those dedicated to digital data. A set of 50 references was used in conducting these studies.

General Bandwidth Compressive Modulation Studies

Much effort was expended researching the merits of various types of bandwidth conserving modulations, as indicated by the Publications Lists, where the papers review the data rate, error rate, and signal-to-noise ratio relationship for various uncoded M-ary digital AM, PM, and combined AM-PM systems. These signal systems have the common virtue that expanding the number of possible signals to be transmitted increases the data rate but not the bandwidth. The increased data rate generally requires an increased signal-to-noise ratio to maintain constant error probability performance. Thus, these systems use power to conserve bandwidth.

Asymptotically, as the number M of possible signals grows, systems for which only one parameter (amplitude or phase) is modulated require a four-fold increase in signal-to-noise ratio to achieve a doubled data rate at constant error rate, while systems with joint modulations of both parameters require only a doubled signal-to-noise ratio.

In the performance of the studies, the concepts of the Gilbert distance and packing coefficient were introduced to permit insight into the relative performances of the various signal systems under an average signal-to-noise ratio constraint. Several bounds on error rates were examined to relate the effects of packing coefficient, Gilbert distance, and Gilbert number on the probability of error. Fairly simple but relatively accurate expressions have been outlined to show the increased signal-to-noise ratio required (relative to binary PSK) for the arrays of signal points considered. Considerable attention was paid to the implementation of transmitter/receiver configurations which will process binary data (both generation of signals and detection of the output binary data stream). Effort was also made to utilize digital processing wherever possible.

One point of interest that emerged from the studies is that MPSK implementation is surprisingly complex (except for quadrature and octal PSK), with receiver complexity increasing sharply with the number of signals. Quadrature amplitude shift keying (QASK) is, by comparison, very simple to implement, and increasing the number of signals requires no added phase references, but only A/D converters which handle more bits. The hexagonal class of signal sets is relatively easy to implement although still more complex than QASK. The remaining systems are very complex to implement.

The joint-modulation class of signal sets with its efficient use of signal-to-noise ratio was examined in terms of relative performance and implementation to permit selection of a preferred signal set. Quadrature amplitude shift keying appeared to be the most cost-effective of this class. It is easiest to implement, and suffers less than 0.25 dB average signal-to-noise penalty relative to the theoretically most efficient.

In terms of QASK receiver synthesis, a decision-feedback structure has been proposed which can be used to provide a carrier reference for any MAPSK signal set, and detailed investigations of its carrier-tracking ability for the case of QASK signals have been conducted.

A pointed need of the QASK receiver synthesis work is that a comparable amplitude-tracking loop would be required in any complete system. The phase-tracking loop characterized has assumed perfect amplitude control. A better approach might include a combined amplitude-phase tracking loop, although implementation might be complex and only marginally better than two separate phase and amplitude loops (because of the high loop signal-to-noise ratios). Further work in this area is justified if practical, efficient, low-cost receivers are to be realized.

PLANS FOR FY'74

In support of OA's consulting role to other government agencies, a continuation of the basic research into the QASK system is planned. The two specific objectives are:

(1) The detailed design, analysis, and performance testing through simulation and breadboard hardware, of the various attendant modulation, demodulation, detection, and synchronization subsystems requisite to the complete QASK system. The result of this work is fundamental to the basic QASK System efficiency evaluation.

The next problem that requires immediate detailed investigation is that of automatic gain control (AGC) because of the inherent amplitude variations from symbol to symbol. The AGC subsystem must be designed to stabilize the nominal operating point of the receiver without responding to the normal amplitude variations from symbol-to-symbol. Further, it must remain constant, independent of long uncharacteristic symbol strings. The AGC subsystem must, however, be capable of rapid response to absolute signal level changes. Analysis, simulation, and laboratory verification of AGC control loops will therefore be a significant portion of the early receiver development effort.

Once the carrier synchronization and AGC subsystems have been developed, they will have to be combined to access interactive effects. The problems and effects of simultaneous noisy phase and amplitude reference signals will be studied.

The conclusion of the end-to-end QASK system evaluation effort will be total system testing to obtain system efficiency. After this, a preferred design can be specified and design and operating constraints specified.

(2) A study of the problems associated with the implementation and efficiency of an AM/PM transmitter.

It is very important that new developments in transmitter power amplifiers be routinely followed so that the final QASK system design specification will reflect the most advanced and efficient approaches.

It is also necessary that new means of handling old problems such as AM/PM conversion be followed. Phase and amplitude nonlinearities and jitter, and peak power limitations of the transmitter power amplifier will limit the number of bits per symbol possible (i.e. the maximum bandwidth efficiency). The effects of switching transients must also be evaluated.

PUBLICATIONS

1. Lindsey, W.C., and Simon, M.K., "Carrier Synchronization and Detection of Polyphase Signals," IEEE Transactions on Communications, Vol. COM-20, No. 3, June 1972.

2. Lindsey, W.C., and Simon, M.K., "L-Orthogonal Signal Transmission and Detection," IEEE Transactions on Communications, Vol. COM-20, No. 5, Oct. 1972.

3. Lindsey, W.C., and Simon, M.K., "On the Detection of Differentially Encoded Polyphase Signals," IEEE Transactions on Communications, Vol. COM-20, No. 6, Dec. 1972.

4. Smith, J.G., "On the Feasibility of Efficient Multi-Amplitude Communications," Presented at the National Telecommunications Conference, Dec. 1972. Also published as an article in the QTR., Vol. 2, No. 4, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 1973.

5. Simon, M.K., and Smith, J.G., "Hexagonal Multiple-Phase-and-Amplitude Shift Keyed Signal Sets," Submitted to IEEE Transactions on Communications, April 1973.

6. Simon, M.K., and Smith, J.G., "A HEX on MPASK," Presented at the International Conference on Communications, June 1973.

7. Smith, J.G., "M-ary Amplitude-Phase Digital Signals Reviewed," Submitted to IEEE Transactions on Communications, June 1973. Also to be presented at the International Telemetry Conference, Oct. 1973.

8. Simon, M.K., and Springett, J.C., "The Theory, Design, and Operation of the Suppressed Carrier Data-Aided Tracking Receiver," TR-32-1583, Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1973.

LAW ENFORCEMENT COMMUNICATIONS NETWORKS

NASA RTOP 164-06-59

W. F. Arndt

OBJECTIVE

The long range objective is to design, develop and experimentally demonstrate communication networks that will meet the information transfer needs of the Nation's law enforcement agencies over the next decade. The work is to be carried to the point where detailed hardware specifications for integrated networks can be written. For the current fiscal year the objectives are (1) to develop smooth working relationships with user agencies, (2) to define user communication problems, (3) to select specific problems for solution with available resources, and (4) to formulate alternate conceptual designs for law enforcement communication networks.

PROGRESS

Initial manpower assignments were made in November 1972. Literature surveys were started. Preliminary analyses in one area, mobile radio communications, were made.

Contacts were established with Project SEARCH and the California Office of Emergency Services, both in Sacramento; the FBI, Bureau of Customs, and the Immigration and Naturalization Service. However, the RTOP was terminated on March 31, 1973, at the direction of the NASA Office of Applications.

PUBLICATIONS

None

COMMUNICATION SATELLITE ANTENNA RESEARCH

NASA RTOP 164-21-54

W.F. Williams

OBJECTIVE

The objective of this work is to develop design techniques for spacecraft communications antennas with multiple beams, or contoured beams with low sidelobes.

Future communications satellites will be required to have much improved performance over those presently in use. Communication directly to small and inexpensive community ground systems, or even directly to users, implies a large increase in the amount of traffic accompanied by a requirement for much increased effective radiated power (EIRP). This will give rise to significant problem areas in the design of these spacecraft. For example, increased traffic implies the use of additional spectrum within that allotted for this use. It is now anticipated that future domestic requirements will exceed the available spectrum set aside for communications use. An increase in EIRP indicates more intense fields at the earth surface and these will likely be near the maximum level specified by international agreement. Also, achieving this higher EIRP is a problem for both transmitter and antenna development.

The shaping of antenna beams to illuminate only certain restricted earth areas offers an answer to some of these problems. A relatively high and uniform gain may be maintained over a region to help achieve the required EIRP, while successful shaping will reduce radiation into unwanted areas (i.e., Canada or Mexico) to acceptable limits.

The use of many isolated beams offers an answer to the problem of spectrum conservation. Beams that are sufficiently isolated from one another could use the same carrier frequency and each such use would double the utilization of that particular band. The use of a multiplicity of shaped beam antennas would then appear to answer many problems. However, space to install and use the anticipated number required will not be available. It follows that there is a need for a single aperture antenna which can generate a number

of shaped beams with a high degree of isolation between certain sets within that number. This states the problem of the Communication Satellite Antenna Research Program study.

APPROACH

The final report for FY'72 discussed approaches to the solution of this problem: (1) use orthogonal beam addition to obtain beam contouring and a resulting planar aperture illumination function, and (2) use spherical wave expansion to decompose a beam into coefficients and expand these to an aperture to obtain illumination, or through a reflector to obtain a feed illumination function. In FY'73, these approaches were combined into a series of steps leading toward the solution of the problem as a reflector system. This combination consists basically of using orthogonal beam addition to generate the contour pattern data, data that represents a realizable electromagnetic field, and using spherical wave expansion to expand the data to a reflector focal point to determine a feed pattern.

PROGRESS

An objective of this fiscal year's work was to exercise the series of programs developed in earlier fiscal years on a sample contour problem. Before this could commence, new programs had to be prepared and some existing programs needed modification. This work was:

(1) Prepared a contour mapping program. This calculation plots geographic areas as seen about a boresight (antenna) axis.

(2) Prepared a contour pattern plotting program for use with sums of azimuthal modes.

(3) Modified a program which decomposes a pattern into its azimuth modes. The modification increased the capacity to many more modes.

When this work was complete, the sample contour problem was started.

The eastern time zone, U.S.A., was chosen as the geographic area upon which to shape a pattern. A satellite position was chosen (the same as the

Lockheed work of 1972) and the contour map was drawn in antenna coordinates. The beam addition program was used to obtain the physical pattern data of a real field. Seven "trial and error" calculations were required to achieve an acceptable contour. This pattern data was then decomposed into azimuth modes, and contour plots of various mode sums were made. It was noted that about 30 modes were needed to give good reproduction of the eastern time zone. The individual mode patterns were then obtained.

It was decided to use only ten modes in the following expansion and scattering programs because of the present expense of operating the scattering program, although this may be improved at a later date. Therefore the spherical wave coefficients were determined for these ten modes, the 0, 1, 2, 3, and 4 even modes and the same number on odd modes.

For the first run through the next program sequence, only the 1-even mode was used. A scale of 1/10 was used to reduce computer costs and this mode was scattered from the back of the parabola (convex side). The resulting pattern is the required feed pattern. Coefficients of this were then determined and the results scattered from the paraboloid in the normal manner. The result should reproduce the original 1-even mode of the original contour pattern. Results were most satisfactory.

Additional runs were made using fewer numbers of coefficients of the original pattern. These were much poorer and indicate the level of coefficient needed.

PLANS FOR FY'74

A program must be prepared for adding the final mode feed patterns to obtain the required feed pattern. This will be a relatively complex pattern, having both asymmetrical contouring parts (azimuth or ϕ variation) and asymmetrical shaping parts (polar angle or θ variation). Also there must be developed a technique to design a feed for giving this pattern, and hence, completing the design of the shaped or contoured beam antenna. One approach to this will be to use orthogonal beam addition. A feed size will have been established when

determining mode feed pattern coefficients. This size may then be used, with its assumed orthogonal beams, for beam addition to achieve the pattern requirement. For this case it will be necessary to develop a program which will solve for the individual complex beam excitation coefficients which would be needed to obtain the final feed pattern, using beam addition. For this part of the work, there may be visualized an actual array feed consisting of perhaps open-ended guides or horns. A solution of orthogonal beam addition will give the exact complex excitation for each waveguide to obtain the final feed pattern.

PUBLICATIONS

None

APPLICATIONS MISSION THRUSTER STUDIES

NASA RTOP 164-76-53

L.B. Holcomb

OBJECTIVE

The objective of this RTOP was to conduct thruster tradeoff studies directed toward characterizing thruster behavior applied to spacecraft attitude and period control, and to develop figures-of-merit for optimal thruster system applications for use by program planners.

PROGRESS

Two specific efforts, which were previously reported under this RTOP, were performed during FY'72 in accordance with the established objectives: (1) an in-depth mission-oriented attitude and station-keeping thruster trade-off study, and (2) a detailed review of auxiliary propulsion system.

The original JPL Technical Report (TR 32-1505) provided a thruster trade-off criteria for spacecraft attitude and station-keeping propulsion and established a common parameter with which meaningful comparisons and evaluations can be made for specific missions.

The efforts accomplished during FY'73 were the study of auxiliary propulsion for the ATS-H satellite and the publishing of a JPL Technical Memorandum on European auxiliary propulsion. Several candidate auxiliary propulsion systems (including chemical and electrical propulsion options) were compared for application to an Advanced Applications Technology Satellite (ATS-H). This work is presented in the Supplement to JPL TR 32-1505. Several aspects of auxiliary-propulsion system selection not discussed in detail in the original Technical Report were studied. These include methods used for the approximation of spacecraft disturbance torques, and their associated propulsion requirements, along with the equations and data necessary to compute the propulsion requirements for tipoff rate reduction, acquisition, commanded turns, north-south station-keeping, east-west station-keeping, solar pressure orbit perturbations, and station changing. In addition, the sensitivity of system comparisons to mission assumptions was considered in detail.

A Technical Memorandum titled "European Auxiliary Propulsion - 1972," published early in FY'73, discusses the present state of the art of auxiliary propulsion in Europe with detailed discussions of auxiliary propulsion development activities in France, Germany, and the United Kingdom.

All efforts planned under this RTOP were completed during FY'73 and the results have been documented in detail in the referenced publications.

PUBLICATIONS

1. Holcomb, L.B., and Lee, D.H., "Survey of Auxiliary Propulsion Systems for Communications Satellites," AIAA Paper 72-515, AIAA 4th Communications Satellite Systems Conference, Washington, D.C., April, 1972; to be published in AIAA Progress Series in Astronautics & Aeronautics "Communications Satellites, Vol. II Technology of Subsystems."

2. Holcomb, L.B., "European Auxiliary Propulsion - 1972," Technical Memorandum 33-555, Jet Propulsion Laboratory, Pasadena, Calif., Sept,, 1972.

3. Holcomb, L.B., "Application of Selection Techniques to the ATS-H Satellite," TR 32-1505 Supplement, Jet Propulsion Laboratory, Pasadena, Calif., Oct., 1972.

SOLID PROPULSION TECHNOLOGY

NASA RTOP 180-32-52

J.W. Behm
W.L. Dowler
Y. Nakamura

OBJECTIVE

The objective of this work unit was threefold: (1) to conduct thermal and thrust-vector-control (TVC) system analyses for the spacecraft energetic propulsion (SCEP) concept using the conesphere motor, (2) to formulate conceptual designs of heat-sterilizable motors for a Mars surface sample return mission, and (3) to assess the ability of state-of-the-art motors to withstand storage in the space vacuum environment.

PROGRESS

Spacecraft Energetic Propulsion

A simple, thermal mathematical model for critical regions of the conesphere motor was developed to determine the requirements for insulation to protect the propellant from being heated by the hot case. (The case, being all carbon, can withstand the flame temperature during firing as well as temperatures due to heat conduction during the heat-soak period between the burnout of one motor and the ignition of the next stage.) The results indicate that minimal insulation will be required for both of these conditions, and if the propellant burning rate and grain configuration can be optimally selected, then possibly no insulation will be required. Elimination of insulation leads to increased mass fraction which is significant in that the prior design included a provision for considerable insulation-weight.

Analysis indicates that head-end steering TVC, with the TVC being part of the payload, is feasible and can be incorporated to provide a three-axis stabilized staged vehicle. The spacecraft energetic propulsion concept now has three options: 1) spin stabilized, 2) spin stabilized followed by despin using electric thrusters, and 3) a fully three-axis stabilized system; with these possible mechanizations the motor development is essentially independent of the stabilization method.

Heat-Sterilizable Motor Conceptual Design

Solid motor applications for a Mars surface sample return mission in the post-Viking period were identified as follows: first stage ascent motors, second stage ascent motor, trans-earth injection stage, and earth-orbit-capture deflection-motor. Figure 1 presents an equipment layout arrangement of the subject motors with respect to related space vehicle subsystems.

A representative design of a heat sterilizable solid motor proposed for use in the space vehicle stages is presented in Fig. 2. Each of the proposed motors is a linear scale-model of the others so as to substantially reduce development and qualification costs. The propellant grain is contained within a rubber boot which in turn is secured to the case by flexible rubber seals. Thus, the grain is free-floating within the rocket motor case to accommodate differential expansions due to the stringent heat sterilization and thermal environmental conditions associated with the mission. A fluid fills the volume between the propellant grain boot and case insulation and cushions the grain as it is held in position against the forward closure by nitrogen gas. The free volume of the motor is gas-pressurized so as to overcome dynamic forces encountered by the propellant grain during normal mission life. The motor case is titanium and the submerged nozzle is an all-carbon composite. Nozzle closure (pressurant gas seal) takes the form of a burst diaphragm that is ruptured upon stage ignition.

ΔV requirements and selective design characteristics corresponding to each of these propulsion maneuvers are presented below for a typical mission mode.

Stage	ΔV, m/s (fps)	Propellant Weight, kg (lbm)	$\frac{L}{D}$ Ratio	Expansion Ratio, ϵ
First stage ascent motors (3)	2290 (7500)	188 (415)	1.0	80
Second stage ascent motor	2430 (7970)	203 (448)	1.0	80
Trans-earth injection stage	1220 (4000)	56.7 (125)	1.0	80
Earth orbit capture deflection motor	2900 (9510)	11.6 (25.6)	0.74	50

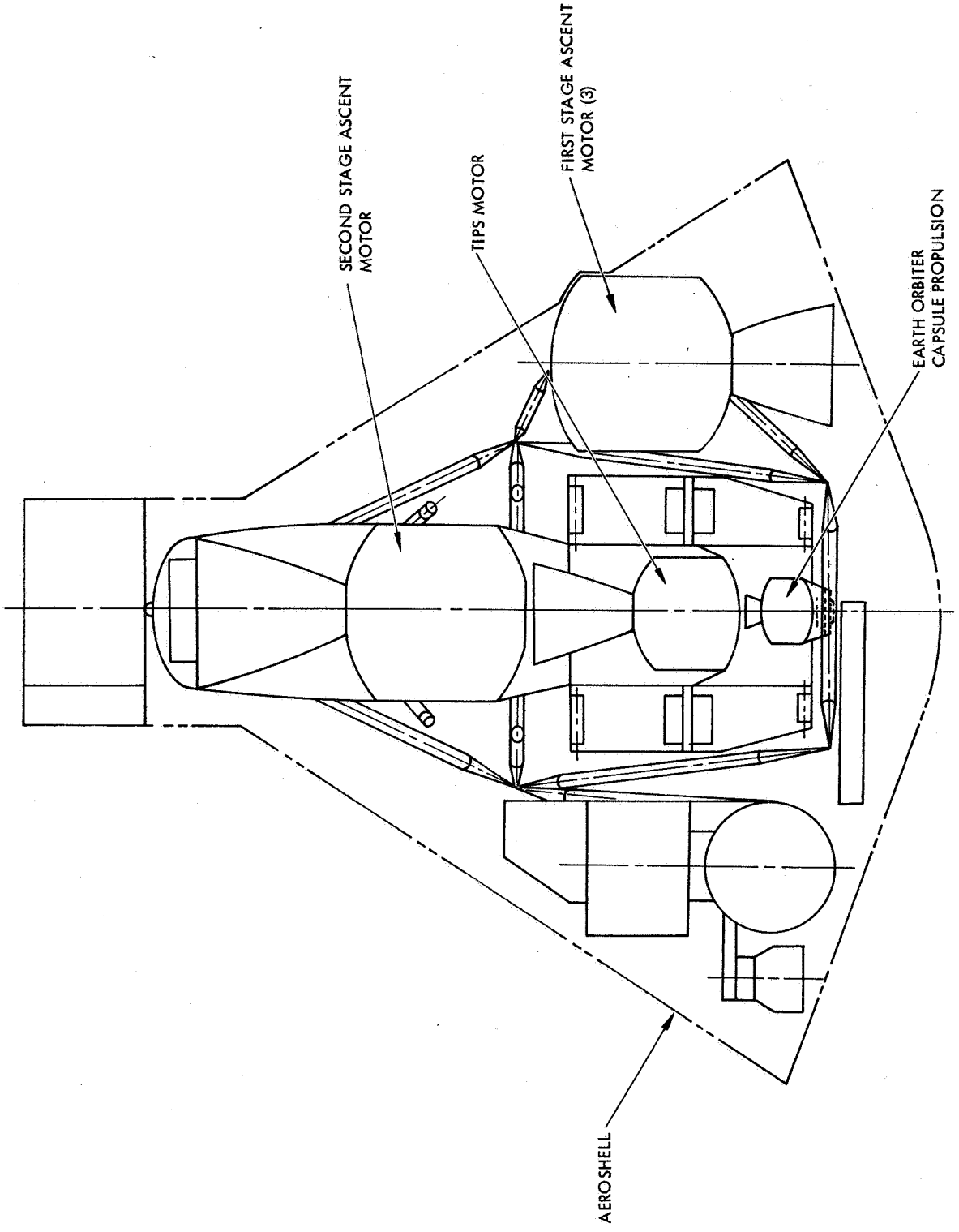


Figure 1. Post Viking Mars Study Space Vehicle

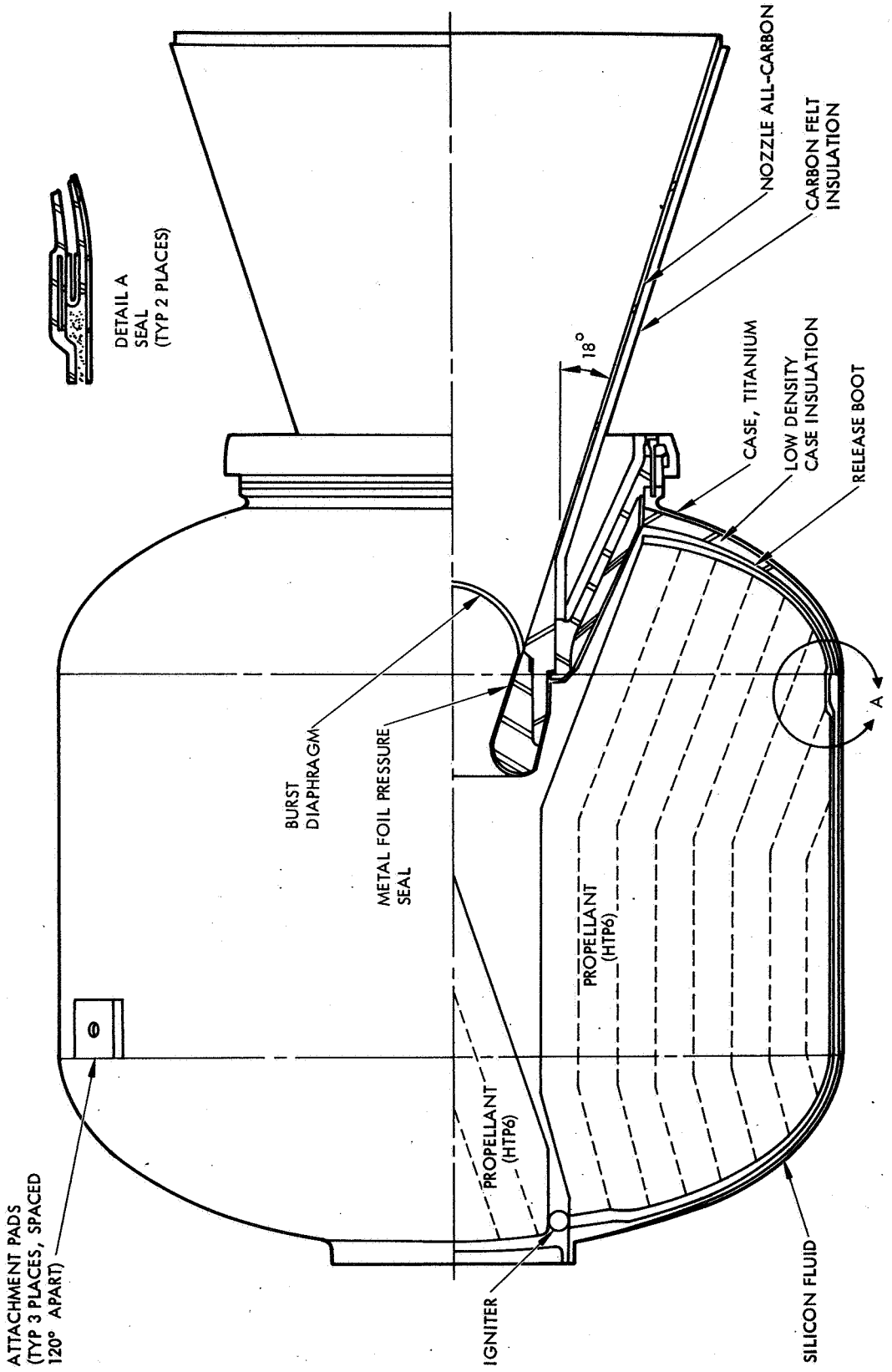


Figure 2. PVM Solid Rocket Motor Preliminary Design

Space Storability of Solid Rocket Motors

This motor storability analysis, based on the Pioneer Venus Orbiter mission, has been completed except for final editing of the report. Two motors from industry were considered in the analysis: SVM-2 (Aerojet Solid Propulsion Company); and TE-M-616 (Thiokol Elkton Division). The conclusions of the study are as follows:

(1) Both solid rocket motors, with perhaps the minor modification of a nozzle seal, would function reliably after 200 days exposure to deep space vacuum.

(2) Also, based on a review of available data, either candidate motor probably could perform the mission without the addition of a nozzle seal; however, an effective nozzle seal would increase structural grain reliability and enhance motor ignition characteristics. Design differences between the motors being considered could result in small differences in probability of success if nozzle seals are not incorporated.

(3) Planning to insure care in sample storage and handling after vacuum exposure must be provided for any future experimental program to obtain meaningful data. It has been shown that where small losses of moisture may be significant in causing material property changes, almost total restoration of properties can occur quite rapidly ($\simeq$ 24 hr) when the material is reexposed to ambient conditions.

PLANS FOR FY'74

None. This work unit is not funded for this period.

PUBLICATIONS

None

Apogee Motor Reliability

OBJECTIVE

The objective of this work unit was threefold: (1) to conceive a simple, readily integratable, diagnostic-instrumentation-module capable of providing information in the event of a flight anomaly or failure of an upper stage, earth-satellite rocket motor; (2) to perform a survey of available surplus flight rocket motors which could be tested in a program to yield reliability or margins information, and to assess user interest relative to such a program, and (3) to determine the systems and environmental effects on the reliability of apogee or upper stage motors through an analysis of selected past flights with anomalous performance which implicated the solid rocket motor.

PROGRESS

Solid Motor Diagnostic Instrumentation

All technical work associated with this study has been completed and a draft report summarizing the findings has been prepared.

Two candidate special-purpose solid motor diagnostic instrumentation systems have been identified to monitor the performance of solid rocket upper stage and apogee motors. Flight diagnostics to be monitored include the output of three-axis accelerometer, pressure transducer, and temperature sensors. Each of the candidate designs is completely independent of the spacecraft power and radio systems (with the exception of turn-on signal) so that failures in these other systems can be distinguished from propulsion failures. Additionally, each system emphasizes the use of state-of-the-art technology and hardware as well as compatibility with existing ground receiving facilities to minimize costs.

The first design consists of a hybrid package that is capable of providing sampled real time data and high-resolution rate sensitive information in a non-real time mode. The design philosophy of this approach emphasizes telemetry performance margin and maximizes the probability of data retrieval regardless

of the nature of the failure or resultant environment. Total weight and volume of the baseline design are 4.94 kg (10.9 lbm) and 0.0097 m^3 (0.34 ft^3), respectively. Associated costs include a $240K development effort and production unit costs of $46.5K in lots of 50 to 100 units.

The alternate system provides real time data and is lighter, smaller and cheaper than the baseline system. However, diagnostic coverage for the alternate system is not comparable to that provided by the baseline system. Although the unit is somewhat limited by the frequency response and loss of signal in the event of a catastrophic failure, the resultant coverage is expected to suffice in the majority of cases. Corresponding weight and volume of the alternate design are 2.45 kg (5.4 lbm) and 0.0026 m^3 (0.09 ft^3), respectively. Developmental costs of $120K and production unit costs of $16.65K were determined for production lots of 50-100 units.

Assuming the diagnostic coverage is deemed adequate for those missions in which weight and cost considerations predominate, it is recommended that the real time alternate design be employed. Conversely, for mission applications in which weight and cost constraints do not preclude the realization of maximizing the probability of data return, the baseline hybrid system is recommended.

Surplus Solid Rocket Motor Survey

JPL subcontract 953298, "Failure Analysis of Solid Rocket Apogee Motors," with the Stanford Research Institute, Menlo Park, California, was modified in July 1972 to include a solid rocket motor availability survey task with objectives as noted above. Questionnaires were sent to various government agencies, NASA Centers, spacecraft prime contractors and rocket motor manufacturers concerning surplus motor availability, recommended tests, and costing aspects.

Principal owners of surplus motors were the Air Force and NASA; a few specific upper stage and apogee motors are owned by JPL, Philco-Ford, Comsat and Hercules. Nearly all motors shown to be surplus are available due to their having exceeded the warranted shelf life. Ages range from 3 to 20 years with

most falling into the 5- to 10-year group. Two apogee and one upper stage motors are considered flight-worthy; perhaps a dozen motors in all are known to be defective; the remaining are considered in unknown condition at this time. Static test fixtures and shipping containers generally are available. Some manufacturing, inspection and test records are available with the motors; the sources are known for those records not currently accessible. The expressed preferences for tests included testing at nominal flight conditions, at the design limits; and to establish margin limits. The principal failure modes of interest are case bond separation and grain bore cracking.

Performance and other principal data on the available motors cover a wide range. Double-base, composite modified double-base, plastic, acrylate, polysulfide, polyurethane, PBAA, CTPB and PBAN propellants are contained in the motors, as case-bonded or cartridge-loaded grains. Steel, carbon, graphite, and silver-infiltrated tungsten throat inserts are available in the nozzle. Case materials include several steels, titanium, aluminum, and filament-wound glass.

Data concerning available solid rockets were summarized in three classes: (a) upper stage and apogee motors; (b) sounding rockets and launch vehicle motors; and (c) JATO sled and tactical motors. Very few upper stage and apogee motors are available; it would appear that an insufficient number of individual motors exist to formulate a meaningful reliability test program. Three or four different launch vehicle auxiliary motors are available in sufficient numbers to support a test program. The design characteristics of these motors would appear to be applicable to future Shuttle auxiliary solid motor needs. In the case of the JATO sled and tactical motors, insufficient information and testing insight have been derived to assess the utility of these units.

Systems Effects on Apogee Motor Reliability

During the FY'73 final year of this study, an examination was made of storage, shipping and handling practices employed in motors utilized in five flight missions where the solid rocket was a suspected cause of failure (Intelsat II–SVM-1 motor, Scout 151C–FW-4S motor, Delta 71–TE-M-364-3 motor, Intelsat IIIH–SVM-2 motor, and IDCSP/A–TE-M-527 motor). Motor

histories, from completion of fabrication to the time of launch, were requested from the respective project offices. Both successful flight motors and flight failure records were compared, where available, to determine if peculiarities in solid rocket motor environmental ground exposures could be identified.

Based on available information it was concluded that:

(1) There is limited evidence that past flight failures involving SP motors have been related in some cases to service demands which exceeded the specified and/or demonstrated capabilities of the motors. Of particular concern are violations of specified storage and transportation requirements, including the storage lives of the motors.

(2) There is strong evidence of a relationship between past flight failures involving SP motors and the storage age of the motors. Specifically, motors involved in past flight failures had been in storage for a significantly longer period of time, on the average, than motors of identical design which later were flown successfully.

(3) There is limited evidence that the relationship between past flight failures involving SP motors and the storage age of the motors might have been due in part to physical damage caused by environmental extremes and/or rough handling of the motors during their relatively long storage and transportation histories. Related to this conclusion is the fact that there appears to have been a surprising lack of care in the control and monitoring of potentially damaging environmental factors during storage and transportation.

Recommendations to flight projects relative to future control and monitoring of solid flight motors prior to launch installation include:

(1) It is recommended that every effort be made to reduce the total time between manufacture and flight use of solid rocket motors. In particular, there appears to be an added risk involved in the use of rocket motors which have been in storage beyond the maximum specified storage life.

(2) It is recommended that at least three critical environmental factors (temperature, humidity, and transient acceleration) be monitored continuously throughout the storage life of the motors, to verify that predetermined limits were not exceeded. Temperature monitoring might be accomplished by the use of simple heat-sensitive decals which change color if a predetermined temperature is exceeded during an exposure period. Similar simple devices are available for the detection of humidity extremes. Transient acceleration could be monitored by a simple seismic mass which trips mechanical switches at predetermined acceleration levels. More sophisticated monitoring equipment would be desirable if funding permits, however, the simple devices described are inexpensive and require no power or maintenance, hence would provide valuable verification of possible motor damage due to environmental extremes during storage and transportation.

PLANS FOR FY'74

The following plans have been formulated:

(1) To submit the draft report on solid motor diagnostic instrumentation to representative sectors of the user community for review, interact with the response of the user community and revise and publish the final report.

(2) To develop and implement a meaningful small sample reliability test program to establish margins using available surplus motors and recent small sample statistical analyses.

(3) To complete and issue the report on the systems effects on apogee and upper stage motor reliability.

PUBLICATIONS

(1) Martin, P.J., "Failure Analysis of Solid Rocket Apogee Motors," SRI Final Project Report 1614, JPL contract 953298, Stanford Research Institute, Menlo Park, Calif., Sept., 1972.

LIQUID PROPULSION TECHNOLOGY
NASA RTOP 180-31-52
R.W. Riebling

OBJECTIVE

The primary objective of this RTOP is to evaluate and demonstrate the applicability and adequacy of state-of-the-art propulsion technology to the spacecraft propulsion requirements of near-term planetary missions. The specific technology areas currently being studied are:

(1) A pressure-fed earth-storable bimodal rocket engine for unmanned planetary spacecraft applications. This engine will be operable on command either as a catalytic monopropellant hydrazine thruster for low-impulse maneuvers such as trajectory corrections and minor orbit modifications, or as a bipropellant thruster, post-combusting N_2H_4 decomposition products with liquid N_2O_4 for larger impulse maneuvers such as orbit insertion. In the monopropellant mode, the engine will operate at one-third of its bimodal full thrust level with a multiple restart capability and a minimum operating lifetime of 2000 sec, including 1000 sec of bipropellant operation. The engine is to be developed to flight prototype status by 1975, so that it could be incorporated into spacecraft scheduled for launch in the 1979-1981 period.

(2) A bimodal propulsion system which can be ready for use by 1979-1981 flight projects. System requirements for the next decade, as well as existing and projected capabilities, will be reviewed. Component improvements, technology deficiencies, and other new approaches will be identified while coordinating closely with related OAST R/AD RTOPs.

PROGRESS

Earth-Storable Bimodal Engine - R.W. Riebling

Thirty-eight firings, totalling 811 sec of accumulated duration, were made in the monopropellant mode and 31 firings, totalling 181 seconds, were made in the bipropellant mode using the highly-instrumented, modular bolt-up

engine discussed in last year's annual report (Document 701-171). Additional performance and heat transfer data were obtained as functions of mixture ratio and chamber configuration for two injectors, a triplet and a coaxial design. The sea level test results, when extrapolated to vacuum at a 60:1 expansion area ratio using standard JANNAF/methodology, indicated a bipropellant performance of 3040 N-sec/kg (310 lb_f-sec/lb_m) with no film cooling with the coaxial injector, which was selected as the baseline injector for subsequent work.

A gas-film-cooled, thin-walled columbium chamber designed and fabricated at JPL then was mated to the work-horse annular catalytic reactor and coaxial injector and fired in a second test series with variable quantities of film cooling to measure performance and heat transfer as a function of the fraction of decomposed fuel gases used as film coolant. Six firings, totalling 151 sec of accumulated duration, were made in the monopropellant mode, and 5 firings, totalling 163 sec, were made in the bipropellant mode. The longest bipropellant mode firing lasted 72 sec. All tests were successful. Sustained thermal equilibrium, at wall temperatures (~2600 °F) well within the capabilities of the columbium alloy, was demonstrated. A bipropellant vacuum performance of 3020 N-sec/kg (308 lb_f-sec/lb_m) at 60:1 expansion was indicated with 9-1/2 percent of the fuel gases used as film coolant, based on the same JANNAF extrapolation technique mentioned above.

Contract 953530 was let to Bell Aerospace Co. for the study and analysis of both regeneratively-cooled and film-cooled thrust chambers. Preliminary design layouts and weight estimates were prepared for engines cooled by both methods. The results indicated a film-cooled chamber would weigh less, and be simpler and less costly to fabricate than a regeneratively-cooled chamber. Based on these results and those of the JPL columbium chamber firings, the film-cooled chamber was selected for development to flight prototype status.

Design layouts have been completed on a preprototype engine, and detail design is in progress. The preprototype is flight-like and flight-weight in most respects, but is highly instrumented and has several bolted joints to facilitate post-test hardware inspection. A cutaway view is shown in Fig. 1. The design features 6 Mariner Venus/Mercury (MVM) '73 type catalytic reactors, modified

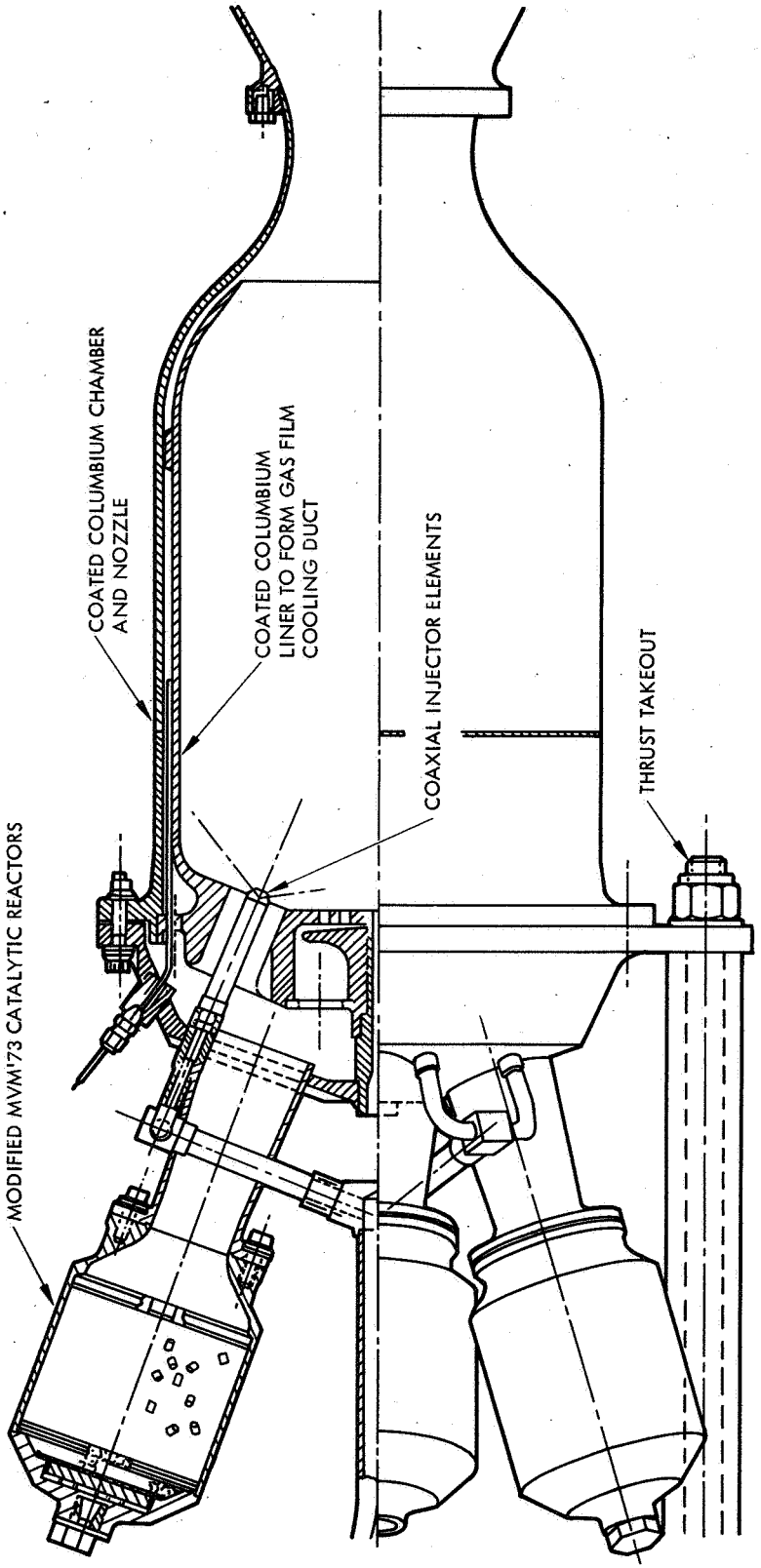


Figure 1. 950-lb_f N_2O_4/N_2H_4 Preprototype Bimodal Engine

in their inlet and outlet fittings, which provide decomposed hydrazine gases for monopropellant mode operation, and 12 coaxial liquid nitrogen tetroxide injector elements for bimodal operation. About 10 percent of the reactor gases pass through an annular duct to film-cool the chamber walls. The prototype engine will be similar to this, except for all welded construction. It is expected that many preprototype components can be modified and used again in the fabrication of the prototype engine.

Plans for FY'74 include testing the preprototype engine to typical propulsion system duty cycles, and converting it to the prototype for prequalification testing.

Bimodal (Formerly "Dual Mode") Propulsion System - P.I. Moynihan

A baseline N_2O_4/N_2H_4 propulsion system compatible with the bimodal engine concept has been defined, and is represented schematically in Fig. 2. This arrangement consists of a separate pressurization and regulation scheme for each propellant tank to ensure maximum reliability over a long-life, extended duration mission. The scheme permits additional monopropellant operations throughout the mission without disturbing either the oxidizer side or the bipropellant mixture ratio. This concept also assumes the integration of a hydrazine attitude propulsion subsystem in common with the fuel tank. The required components for the baseline system have been identified and, in conjunction with a propulsion system pressure budget, a system mass breakdown by component has been defined. The propulsion system scaling equation, which is necessary to size this system to different spacecraft for various potential missions, was then derived from the resulting mass and pressure budget.

Mission application studies and tradeoffs were continued to identify specific missions for which this propulsion system would be both applicable and desirable. As an example, the bimodal system became the baseline propulsion system for the Venus Orbiter Imaging Radar study, and appears highly desirable for application to an improved Mars Orbiter in either 1979 or 1981, e.g., Viking-class missions. Calculations show that it would be feasible to adapt the 4450 N (1000 lb_f) bimodal engine to the existing Viking Orbiter '75 propulsion system with minimal changes to existing Viking hardware, although

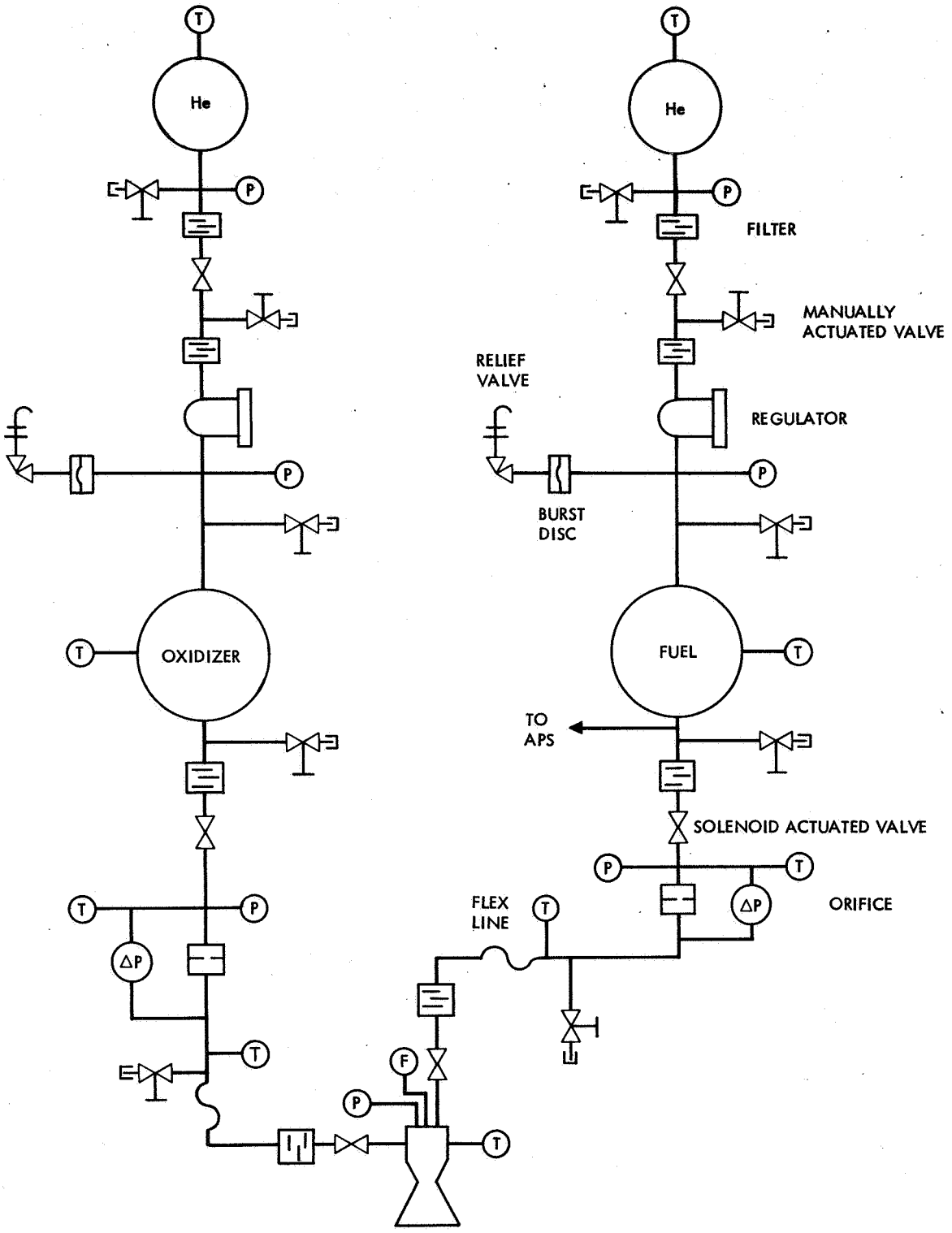


Figure 2. Schematic Representation of Baseline N_2O_4/N_2H_4 Bimodal System

this system would differ schematically from the previously discussed baseline bimodal concept in that the Viking system has common pressurant tankage. The mission analyses and system tradeoffs have interacted with the engine development by aiding in the establishment of target design and operating parameters.

PLANS FOR FY'74

The following activities are planned:

(1) The system analyses will be continued, with heavier concentration on the 1979 and 1981 Mars Orbiter (Viking-class) missions.

(2) A "slaved" regulator concept for the separate pressurization scheme will be defined and breadboarded as a means of avoiding the necessity of the high cost development of extremely precise regulators that could operate independently. (Present state-of-the-art regulators are not sufficiently accurate to maintain the required close tolerances.)

PUBLICATIONS

1. Kruger, G.W., and Riebling, R.W., "Experimental Evaluation of Performance Losses in Monopropellant Hydrazine Reactors Using Shell 405 Catalyst," paper presented at 1972 JANNAF Propulsion Meeting, New Orleans, LA., Nov. 28, 1972.

2. Dodge, C.H., Riebling, R.W., and Nunz, G.J., "Experimental Evolution of an Earth-Storable Bimodal Rocket Engine," AIAA Paper No. 72-1128, presented at AIAA/SAE 8th Joint Propulsion Specialist Conference, New Orleans, LA., Nov. 30, 1972.

MISSION REQUIREMENTS FOR NUCLEAR ELECTRIC SPACECRAFT/ELECTRIC PROPULSION RELIABILITY

NASA RTOP 180-06-51

J. W. Stearns
D. G. Elliott

OBJECTIVE

The objective of this work is the design investigation of the consequences of using electric propulsion to provide prime power aboard planetary spacecraft or stages. Emphasis is placed on integration problems and their solutions, mission operations and controls, and reliability and safety.

Through mid-FY'73, the focus of the program was on nuclear power with electric propulsion (NEP). Later emphasis has been on the development of the electric propulsion system/stage reliability code to include solar power sources. When completed, the computer code will allow propulsion system design optimization based on failure mode analysis and mission reliability requirements.

The objectives of the solar electric propulsion reliability study are to: (1) select the best available methods and computer programs for calculating solar electric propulsion reliability, (2) modify and adapt the programs as required for the particular application, (3) select values for thruster, power conditioner, solar power subsystem, and other subsystem lifetimes and failure rates, and (4) utilize the reliability programs and subsystem reliability data to arrive at optimum propulsion system arrangements and associated system reliability values.

PROGRESS

A contract with General Electric, Space Systems Organization, was completed in the third quarter of FY'73. Both planetary and geocentric mission applications were considered in the performance of four major tasks:

Task A - Mission Study and Operation Analysis
Task B - Development Schedules and Costs

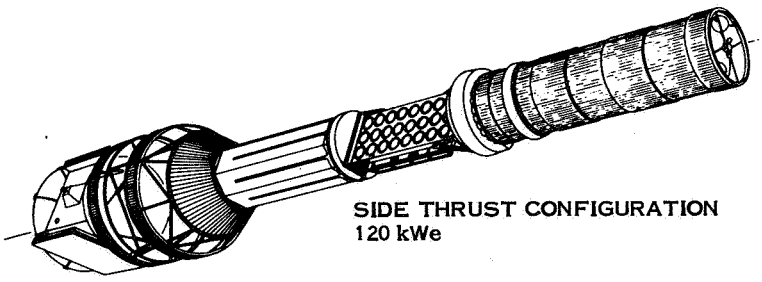
Task C - Multimission Spacecraft Definition
Task D - System Technology Requirements Delineation

The first two tasks (A and B) were completed the previous fiscal year for planetary missions. This work was augmented in-house at JPL in conjunction with the Advanced Concepts and Mission Division of OAST to include large and complex geocentric and planetary missions. It was found from these studies that NEP systems of 240 kWe or greater could be exceptionally valuable for large multi-payload, multi-mission operations. Because of center-of-gravity variations inherent in such missions, an end-thrust NEP stage was configured. as shown in Fig. 1. Ion engines must be canted slightly to minimize exhaust beam interactions. The thermal design also was found to be more complex than with the side thrust configuration.

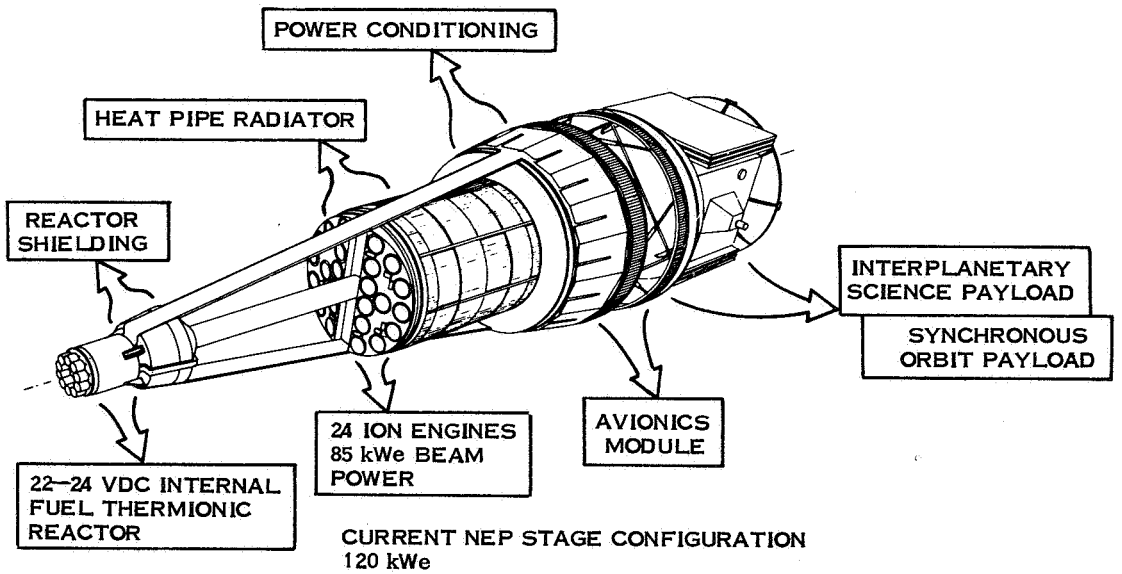
Results of the contracted study are reported in Publication 1. Identified pacing NEP stage technology requirements are the development of 20, 000 full-power-hour ion thrusters and thermionic reactor, and the development of related power conditioning. The resulting NEP stage design provides both inherent reliability and high payload mass capability. The latter may be translated into both low payload cost and high payload reliability. NEP stage and payload integration is shown to be compatible with the Space Shuttle.

A computer program developed for analysis of nuclear powerplant reliability (Ref. 1) was obtained from the AEC, and a program developed for analysis of rocket propulsion system reliability (Ref. 2) was obtained from Princeton University. The two programs provide general mathematical treatments of system reliability and differ mainly in the type of input and output data. It is expected that one or a combination of both programs, together with reliability programs already in use at the Laboratory, will be readily adaptable to solar electric propulsion system reliability calculations.

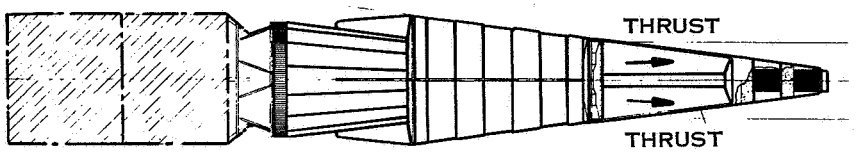
A review of the test history of ion-bombardment electric thrusters was conducted as one approach to estimating lifetime and failure rates. A survey of the reliability of other more highly developed, electronic devices operating at similar temperatures and voltages is also being conducted to arrive at an estimate of ultimate reliability potential.



SIDE THRUST CONFIGURATION
120 kWe



CURRENT NEP STAGE CONFIGURATION
120 kWe



END THRUST CONFIGURATION
240 kWe

Figure 1. NEP Stage Evolution

PLANS FOR FY'74

The available reliability computer programs will be adapted and modified as required. Computations will be made of solar electric propulsion system reliability for typical missions with various propulsion system arrangements for a range of assumed component reliabilities. Preliminary conclusions will be drawn as to best system arrangements, required component reliabilities, and spacecraft weight and mission performance as a function of reliability.

REFERENCES

1. Vesely, W. E., "Analysis of Fault Trees by Kinetic Tree Theory," Report No. IN-1330, Idaho Nuclear Corporation, Idaho Falls, ID, Oct. 1969.

2. Greenberg, J. S., and Telsch, R., "Reliability Compiler, a Reliability Network Processor," ASAR Memo No. 103, Aerospace Systems Laboratory, Princeton University, Princeton, N. J., July 1, 1972.

PUBLICATIONS

1. Nuclear Electric Propulsion Mission Engineering Study, Final Report Document 73SD4219 (Vol. I) and 73SD4220 (Vol. II), March 1973.

2. Shaupp, R. W., Mondt, J. F., and Nakashima, A. M., "Thermionic Reactor System Applications to Electric Propulsion Missions," presented at the 1972 Annual ANS Winter Meeting, Washington, D. C., Nov. 1972.

ENGINEERING INSTRUMENTATION
NASA RTOP 180-24-51

A. J. Murphy

OBJECTIVE

The objective of this applied research program is to develop instrumentation and test techniques to test and evaluate electroexplosive devices (EEDs). Nondestructive test instrumentation which will reveal meaningful information about critical areas of the EED e. g., the bridgewire, is emphasized. Other types of instrumentation to study and observe the dynamic behavior of the initiation process also are included. Although the techniques are developed for EEDs, they find application in other areas e. g., fuses and electronic components. In addition to developing the instrumentation and techniques, it is an objective to introduce them to flight program personnel as well as other manufacturers and users concerned with demonstrating high reliability in EEDs, fuses, and electronic components.

PROGRESS

Dynamic Thermal Coupling Measurement In EEDs

Instrumentation and a method for the measurement of heat flow in an EED have been developed. Low energy electrical power applied to the bridgewire will heat the wire to a few degrees above ambient. Heat generated in the wire must propagate through the explosive and the associated hardware, ultimately ending up in the ambient environment. The heat transfer path is complex. It may consist of many parallel paths or paths which have thermal discontinuities and an assortment of unusual boundaries. Accidentally or intentionally, paths may be opened due to air gaps or material barriers.

Heat flow starts from the wire and in a three-dimensional pattern flows out to the device walls, the ultimate heat sink. The preferred or dominant paths might be considered one-dimensional except in the immediate vicinity of the bridgewire. By employing the bridgewire in a self-balancing bridge, the wire can be raised a few degrees above ambient and the power flowing into the wire

measured directly. Naturally the temperature of the bridgewire must be maintained at a safe low level, far below that experienced in firing the device. At an equilibrium condition, the entire device can be inserted into a hot or cold bath to provide a plus or minus ΔT. The heat flow (watts) pattern is upset, and, at a rate determined by the diffusivity, a new equilibrium condition is obtained. Instead of isothermal perturbation, it is possible to utilize a heated airjet and direct the thermal disturbance along a specific port of entry.

The self-balancing bridge heats the bridgewire to some temperature T and keeps it at that preset temperature (and resistance) by automatically supplying the power required. This power can be measured accurately in watts and as heat is added or removed from the system a distinct power/time curve can be plotted by monitoring the self-balancing bridge output. Several EEDs loaded with different materials have been subjected to the test. Power/time curves, as in Fig. 1, have been obtained which are indicative of the thermal conductivity and diffusivity of the materials loaded into the EEDs.

Narrow High Current Pulse Generator

The most critical area of an EED is the bridgewire/header/explosive interface. The bridgewire acts as an electrothermal transducer accepting electrical energy and converting it to heat, consequently causing ignition of the explosive. The behavior of the bridgewire with various forms of electrical input energies and its coupling to the explosive material are of basic interest because many fundamental factors affecting the initiation of EEDs have not yet been satisfactorily explained. Increased reliability in EEDs can be realized from a thorough understanding of the initiation process.

Considerable data have been accumulated from conventional firings but little is known about the initiation process. It is felt that above 50-A input for 1-W, 1-A, no-fire EEDs, the bridgewire burns out electrically and subsequent electrical arcing is responsible for initiation. Arcing also may occur in the more sensitive military type EEDs at lower current inputs. Little is known about this mechanism and latest data indicate that another current versus time-to-fire relationship may exist.

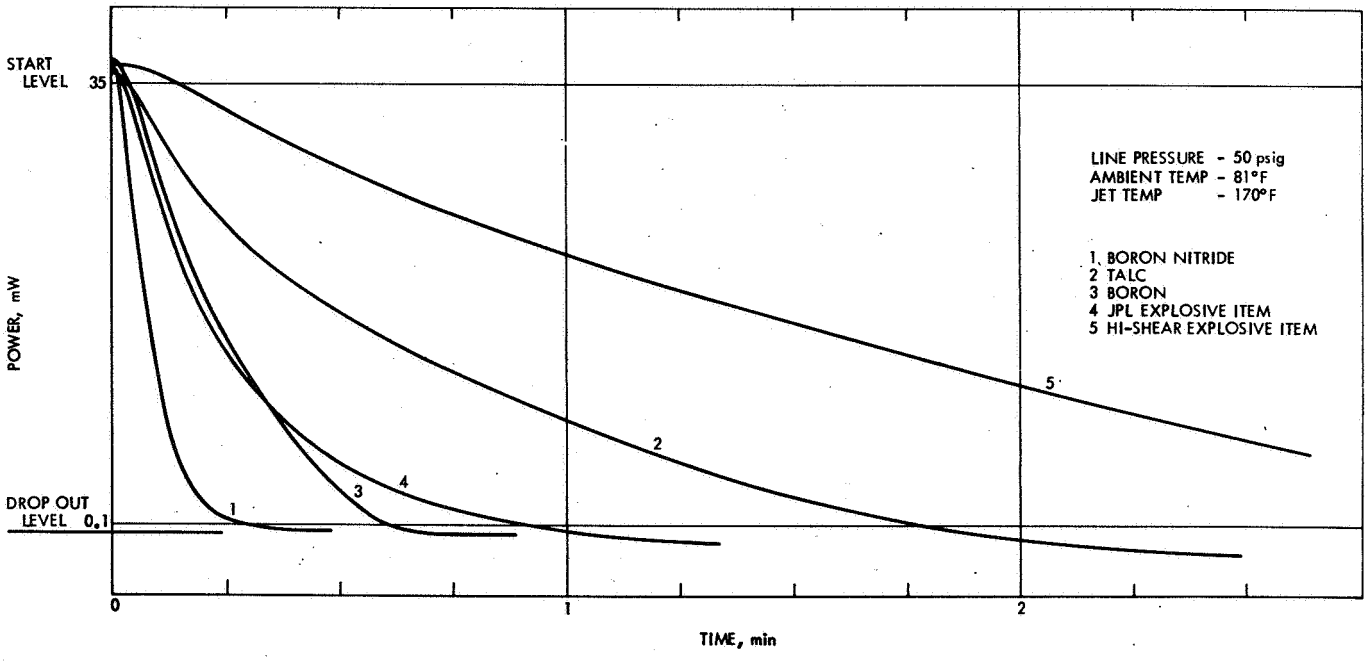


Figure 1. Heating the output end of the explosive results in flow decay curves when starting from an initial power level. A high degree of thermal coupling will result in a rapid fall to drop out.

For extremely narrow pulses, it has been observed that the firing energy increases and a possible explanation is the inability to deliver energy rapidly in a typical electrical firing system. There is some speculation that for very fast energy delivery, degradation of heat transfer to the explosive at the bridge-wire interface may be responsible. A method for delivering large current pulses for times less than 10μsec would be required to study this firing region. A half-sine wave pulser with the capability of these rapid deliveries has been built.

The pulser in conjunction with a high speed framing camera is presently being used to observe the dynamic behavior of a bridgewire under high current heating. The effect of current pulse shape, current magnitude, energy input, and rate of energy input will be determined.

Progress on Dissemination of NDT Techniques

Since the development and reporting of nondestructive test techniques for EEDs, considerable interest has developed with fabricators and users of EEDs. Inquiries have been made by, and discussions carried out with, the Lockheed Missiles & Space Co., Aerojet Ordnance, Special Devices, Boeing, NASA Houston, Allied Chemical and others. In each case the inquiries were directed toward obtaining a test technique which would allow the agency or company to demonstrate a high degree of reliability for its particular EED. It is known that Sandia is building equipment based on the "transient pulse" technique to automatically monitor its EED production and procurement. NASA Langley has built a "transient pulse" instrument similar to JPL's and has it in use. The Allied Chemical Co. is strongly involved in the development of an EED-initiated "air bag," a passive restraint safety system for automobiles. These systems will use and require very high reliability EEDs; the transient pulse test is being considered for this purpose.

PLANS FOR FY'74

(1) Measure the pulse energy delivered to a nonlinear resistor
(2) Develop a reusable squib simulator using light emitting diodes and photographic techniques

(3) Study the feasibility of inflight monitoring of electroexplosive devices

(4) Continue evaluation and testing of the thermal coupling nondestructive test technique

(5) Continue the study of bridgewire behavior of EEDs to various pulsed inputs.

PUBLICATIONS

1. Murphy, A. J., Jr., Menichelli, V. J., "New Tests for EEDs," Ordnance, Nov. - Dec. 1972.

2. Menichelli, V. J., "Nondestructive and Impulsive Testing of Electroexplosive Devices," Journal of Spacecraft and Rockets, Vol. 9, No. 12, Dec. 1972.

3. Menichelli, V. J., Rosenthal, L. A.; "Generation of Narrow High Current Pulses," QTR., Vol. 2, No. 4, Jet Propulsion Laboratory, Pasadena, Calif., Jan. 1973.

4. Rosenthal, L. A., Menichelli, V. J., "Impulsive Firing Method for Electroexplosive Devices," IEEE Transactions on Instrumentation and Measurement, Vol. IM22, No. 2, June 1973.

SCIENCE SUBSYSTEM TECHNOLOGY FOR OUTER PLANET MISSIONS

NASA RTOP 186-68-52

W. M. Porter

OBJECTIVE

The objective of this work is to develop advanced imaging concepts which will yield low-cost, long-life imaging instruments for use on outer planet missions beginning in 1979. To meet this objective, development of feasibility model cameras utilizing new sensors has been undertaken. The initial development was directed toward silicon vidicons. Subsequent activities will be directed toward solid state cameras using charge-coupled sensors. This is a long-term program which will start in FY'74, with the objective of developing a low-cost, general purpose planetary camera system. Simplicity, long life, and high performance are also inherent characteristics of the charge coupled sensor approach.

PROGRESS

The feasibility model of the silicon vidicon camera has been built and evaluated, which completes the work in this area. The following activities, under the joint sponsorship of the 185 and 186 Program Office, have taken place.

Functional Design

Functional requirements were established for the camera, based on the following objectives:

(1) To design, manufacture, and test a silicon vidicon camera capable of slow-scan operation and determine its feasibility for space flight applications.

(2) To determine the packaging requirements of the silicon vidicon which incorporates the thermal, mechanical, optical, and electrical considerations imposed by expected space flight mission constraints.

(3) To gain experience and expertise by actual operation of the camera under simulated mission environmental conditions.

Based on these requirements, an imaging system incorporating a Mariner TV modified to operate with, and to cool, a silicon vidicon was blocked out.

Conceptual Design

The general approach to the design was to modify a Mariner '71 Imaging System to operate with a silicon vidicon. This was done to enable available resources to be applied to the problems which are unique to the operation of a silicon vidicon in a flight-configured camera. The design concentrated in three basic areas: cooling of the vidicon, electrical circuitry necessary for the operation of the vidicon, and modification of the Mariner support equipment to operate the completed silicon-vidicon camera.

The general design approach decided upon for the camera head was to thermally isolate the vidicon from the rest of the structure and cool only it. This represents a departure from earlier concepts which would have cooled all or most of the camera head. While the general approach decided upon appeared the more difficult of the two to implement, it held the promise of requiring a much smaller radiator for cooling and was chosen for this reason.

Three different concepts were considered for cooling the vidicon. The concept that was developed is to isolate the vidicon and a cold front plate assembly from the camera chassis by a large diameter insulating cylinder.

The other concepts which were considered included supporting the vidicon by an insulator from a warm front plate and supporting the vidicon from the inside bore of the coil assembly. In choosing which concept to use, preliminary thermal and structural analyses were made of the different configurations. Additionally, consideration was given to constraints which each configuration might impose upon the electrical design.

In performing the conceptual design, a thermal analysis was carried out considering the heat leaks presented by the candidate designs, probable radiator sizes for each of the designs, and the need for bench operation. The predicted radiator size for the chosen design was 278 cm^2. Radiator sizes for the other candidate designs were predicted as 214 cm^2 and 242 cm^2. The design chosen for development was picked after careful consideration of the relative ease with which each design might be implemented as hardware.

Detailed Design

Close attention was paid to the thermal aspects of the detailed design. The concept chosen to be realized was modeled for a thermal analysis computer program and simulations were run as the details of the design were developed. This allowed for the optimization of the camera head in terms of minimizing heat leaks.

The structural aspects of the design considered survival of vibration levels equivalent to a Mariner launch and thermal stresses and displacements resulting from cooling the vidicon.

The electrical design considered the necessary timing changes to the Mariner support equipment and prototype electronics, as well as the new circuitry required to operate the silicon vidicon. Worst case circuit design techniques were used to insure operation over the full temperature range as well as to insure operation independent of expected component parameter changes.

New circuitry included a hybrid preamp having a 6-dB higher signal-to-noise ratio than the replaced Mariner preamp. The improvement in signal-to noise ratio in the Mariner electronics was made necessary by the fact that the signal current of the silicon vidicon is lower than that for which the electronics were originally designed.

Environmental Test

Testing of the camera concentrated on its ability to operate under space flight conditions and on its ability to survive a rocket launch. No serious effort was undertaken to evaluate the quality of its pictures since the vidicon was evaluated separately under another program.

The first test performance on the camera was to verify its ability to operate on the bench. This was done by evaporating LN_2 in the heat exchanger which attaches to the radiator. The radiator was covered with 2.5 cm of polystyrene form and the camera was purged with dry nitrogen. No trouble was encountered in lowering the vidicon faceplate temperature to the required -40° C.

The camera was first tested in thermal vacuum with a simulated scan platform temperature of +35° C. This resulted in a vidicon faceplate temperature of -58° C against a designed-for temperature of -40° C and a predicted temperature of -65° C for the conditions actually simulated. Subsequent analysis of the temperature data taken shows the heat leak into the camera front plate to be somewhat larger than predicted, possibly caused by degraded low emissivity surfaces.

The initial thermal design for the camera predicted a minimum temperature below -70° C for the vidicon faceplate assuming low spacecraft temperature. Because the structural design considered this to be the minimum temperature, part of the radiator was masked off before proceeding with the testing. This was done as a precaution against overstressing the vidicon or its supporting structure caused by temperatures below -70° C. On the basis of the data taken, all but 130 cm^2 of the radiator were covered with aluminum tape to hold the vidicon to a predicted temperature of -61° C.

After masking off part of the radiator, a second test was run at a simulated scan platform temperature of -20° C. The vidicon faceplate reached a predicted temperature of -60° C.

Vibration testing consisted of shaking the camera along all three axes. First in a 0.5 grms sine sweep from 30 to 2000 Hz at 2 oct/min. Following this, the camera was tested to the flight acceptance and type approval levels which were established as typical of future Mariner launches. In both cases, the sine sweep proceeded the random vibration test. All three axes were tested at the FA levels before proceeding to the TA levels.

The flight acceptance sinusoidal vibration test consisted of sweeping per the specified sinusoidal amplitude levels from the lowest frequency to the highest frequency and back to the lowest frequency at a logarithmic rate of 4 oct/min. The type approval test was similar with a sweep rate of 2 oct/min. The flight acceptance random vibration test levels were applied for 1 min on each axis. The type approval test was similar, applying the test levels for 5 min on each axis. The random vibrations had a gaussian amplitude distribution except that instantaneous peak amplitudes of greater than 3σ were suppressed.

The camera survived all vibration testing intact with the exception that a rear fiberglass support for the radiator broke during testing at the TA levels. This was considered to be of little consequence as this part easily could be made stronger without compromising the overall design. The limit load used for the design of the vidicon support implies an acceleration at the free end of 450 g lateral and 300 g axial. The corresponding acceleration observed at flight acceptance test level was 176 g at 300 Hz and 200 g at 600 Hz.

PLANS FOR FY'74

In 1974, it is planned to switch investigation to the utilization of solid-state charge-coupled imaging devices and associated electronics. To take advantage of the current availability of line array devices, a line scan camera will be implemented first. This will be done such that there is maximum applicability to the area array camera planned for the following fiscal year.

The following objectives are planned for FY'74:

(1) Study of line array sensors and a determination of their status
(2) Line array CCD sensor acquisition and testing
(3) Functional design of a line array camera emphasizing simplicity in both the instrument and the instrument-spacecraft interface
(4) Definition of required support equipment
(5) Camera detailed design

PUBLICATIONS

None

TELECOMMUNICATIONS TECHNOLOGY FOR OUTER PLANET MISSIONS

NASA RTOP 186-68-53

A. R. Galbraith

OBJECTIVE

The objective of this work is to advance the telecommunication device and system technology of the Mariner/Jupiter/Saturn (MJS'77) spacecraft to provide reduced costs and increased lifetime, reliability, and performance for missions to the outer planets in 1979 and beyond. Specific tasks aimed at achieving this objective are: (1) development of an advanced multimission microminiature S/X-band transponder; (2) development of a programmable digital telemetry modulation interface; and (3) a study of the RF noisy reference in the command channel.

The current MJS spacecraft utilizes a Viking Lander S-band radio system augmented with an X-band transmitter. Cost, power, and reliability advantages of the advanced transponder are sufficiently attractive that the MJS'77 Project is also considering this design implemented in a mini-PC board version.

PROGRESS

Microminiature Transponder Development

The transponder development has been jointly sponsored by OAST and this RTOP. A microminiature transponder receiver study contract effort, which was initiated with Motorola in FY'70, has continued through FY'73 at a reduced level.

A beam lead component, microminiature feasibility demonstration breadboard model S-band receiver (short loop, RF front end not included) was delivered to JPL in August 1972. The receiver was integrated with a breadboard ALSEP RF converter for evaluation. Several performance anomalies were observed during receiver evaluation. Module designs were updated to incorporate the required changes to correct performance anomalies. A micromin RF converter design was initiated and completed by Motorola under company funding.

Motorola completed fabrication and test of a revised discrete component receiver utilizing printed circuit board technology for the short loop configuration and ceramic substrate technology for the micromin RF converter. This receiver configuration was utilized as an expedient test vehicle to verify the incorporated design changes. Motorola tests on the receiver were completed in the fourth quarter of FY'73 and are currently under evaluation at JPL. Additional design iterations will be required in several modules prior to fabrication in micromin technology.

Additional beam lead component test fixtures have been fabricated in-house and characterization of sufficient beam lead components has been completed for use in breadboard module and receiver development work.

A second source (Airco-Speer) for beam lead resistors has been developed. with delivery of prototype parts completed. Preliminary evaluation of the resistors is very positive. Additional resistors are being procured from Airco-Speer and Motorola for parts qualification in FY'74.

Ceramic substrate metalization studies and evaluation are continuing at Motorola under company funding, with some limited in-house support, in an attempt to select and qualify a substrate metalization that has the compatibility for all processing steps required in fabrication and assembly of a micromin receiver, which include: batch processing with compatibility for high temperature brazing, soldering, firing of glass materials for hermetic sealing, and thermal-compression bonding. In addition, the metalization must exhibit good adhesion to the substrate material, with little or no adhesion degradation during processing steps. The tentative multi-layer metalization selected is titanium-molybdenum-gold (Ti-Mo-Au). Test results to date are positive and extremely encouraging.

Selected breadboard modules (first IF amplifier and VCO) have been fabricated and tested in-house. The circuit designs have been converted to micromin form utilizing beam lead components. Performance characteristics of the micromin modules have duplicated the breadboard units with the exception of VCO phase noise. This problem is currently under investigation.

A contract has been let with Motorola for micromin technology qualification for deep space applications. A quantity of 16 micromin local oscillator chain modules will be fabricated and environmentally tested to qualify processing techniques, determine design margins, and demonstrate reproducibility. The effort will begin in the first quarter of FY'74.

In-house efforts have produced a complete miniature breadboard S-band exciter consisting of three amplifiers and two frequency multipliers. Test results show an S-band output level of 40 mW is obtained with a DC input power of 750 mW. Microminiaturization of some stages and packaging of the complete exciter are yet to be accomplished. All of the S-band exciter stages will be used with some frequency and power scaling in the X-band exciter. The X8 SRD frequency multiplier has been built on a microminiature ceramic substrate. This multiplier develops an S-band level of 50 mW with a conversion efficiency of 16%. Continued investigation of SRD phase sensitivity of the X8 indicates its additional use as a phase modulator is feasible. Design and breadboarding of the final stage for the X-band exciter has been completed. This ceramic substrate X5 SRD frequency multiplier has a conversion efficiency of 16% at an X-band output power level of 250 mW.

RF Telemetry Modulation Interface

Of the alternative designs under consideration for the programmable digital telemetry modulation interface, the crucial portions of several of the most promising candidates were breadboarded and tested. The candidate which emerged as most attractive was one which uses a monolithic digital-to-analog converter to set modulation index and uses the data ϕ subcarrier to switch the output of the converter on and off to the RF modulator. This switching is done by means of n-channel MOSFET analog switches driven by CMOS logic. Programming of the modulation index is accomplished via a single, serial 8-bit word.

A dual-channel design capable of 256 discrete modulation indices for each channel was breadboarded and tested up through the output of the RF modulator. The test results showed that the effort was highly successful and that all design objectives were met. The waveform integrity to the modulator is excellent; rise

and fall times are each 30 ns; asymmetry is less than 1% at a carrier frequency of 1 MHz.

RF Noisy Reference Investigation

The 1.5-to 2.0-dB unexplained loss in the transponder has been traced to circuits following the 47-MHz IF. Further investigations have verified that the loss is present in both the internal receiver AGC loop and at the dynamic phase error (command) output. The RFS phase detector output form factor and delays due to the receiver bandpass filter were found to contribute insignificant loss. Further investigation of other post IF circuits will be carried out as time and funds permit in order to identify the source(s) of the problem.

PLANS FOR FY'74

Except for the FY'74 costs incurred on the micromin technology qualification contract at Motorola, this RTOP is not being funded in FY'74. A report on the technology qualification is scheduled for March 1974.

PUBLICATIONS

None

GUIDANCE AND CONTROL TECHNOLOGY FOR OUTER PLANET MISSIONS

NASA RTOP 186-68-54

W. Goss

OBJECTIVE

The objective under this task is to develop an advanced reliable long-life image dissector tube for use in the spacecraft roll control star tracker. The image dissector which has been used is based on a glass electron tube technology and has inherently high costs and many technical and fabrication problems. Continued availability is in question.

The new tube is based on modern ceramic electron tube technology and so inherently has advantages of ruggedness and dimensional control and stability. Major improvements in the electro-optical characteristics and stability are expected as well as a greatly improved tolerance of thermal and magnetic environments.

Work planned for FY'73 included fabrication, test and delivery of three tubes by the contractor and submission of drawing and process documentation packages.

PROGRESS

In the latter part of FY'72 it was decided that the design of the brazed metal and ceramic sections would have to be improved because of the high proportion of leaking joints. Accordingly, a ceramic-to-metal seal development was in progress at the beginning of FY'73. A knife-edge-type seal was undertaken by the contractor upon the recommendation of a seal consultant from COMSAT, Dr. Peter Varadi, and structural and metallurgical personnel from JPL. The knife-edge seal allows brazing the ceramic parts to a thin and relatively flexible metal cylinder and so accommodating the rather large thermal expansion coefficient mismatch ($18 \times 10^{-6}/^{\circ}C$ versus $7 \times 10^{-6}/^{\circ}C$). The metal is Monel 404, chosen for its excellent brazeability, weldability and low magnetic permeability. The ceramic is aluminum oxide, 96%.

Sample parts were made, furnace-brazed, vacuum tested and sectioned for evaluation. Vacuum tight parts were achieved, however, sectioning disclosed localized stress cracks in the ceramic. The design was changed to reduce the strength of the Monel parts and the amount of braze was decreased. Sectioning of new seal samples disclosed no stress cracks in the ceramic. The seal has since been used in the fabrication of five tubes, and none of the seals has leaked.

The tube design has since been completed and fabrication drawing and process documentation packages assembled and shipped. Five tubes were assembled in FY'73, one has been delivered, two are now in test prior to delivery and two were lost in process. Each of the two tubes lost in process pointed up a design weakness which was subsequently corrected. In one case copper tubulations which are pinched off to seal the tube after processing were found to experience an excessive stress concentration during pinch-off so that a leak resulted. In the second case the tube was incorrectly supported by encapsulant in the mounting shield and excessive stresses were generated by the encapsulant during a high temperature test.

Delivery of the two tubes now in test, and a final report will complete the contract requirements for delivery of four tubes and documentation. One tube which was built to an earlier design was accepted for delivery in a previous year.

Results of functional testing performed at the contractor's facility show that very significant improvements have been made in photocathode sensitivity, tube stabilization times and dark current levels. Dark current, for example, is typically two to three orders of magnitude less than in the present star tracker tube. Photocathode sensitivity typically is twice as great. Modest improvements in photocathode and first dynode uniformities have been made.

Functional tests have been run at JPL on the one tube delivered to date this fiscal year. The contractor's data were generally corroborated. Additional tests checked performance characteristics not measured by the contractor. Magnetic field retention after exposure has been found to be one tenth or less of the presently-used tube. The new tube has been operated at pressures

varying from atmospheric to hard vacuum without any indication of high voltage corona leakage. Mechanical centering of the tube ceramic and housing pieces has been checked and parts are concentric within 0.06 mm.

One significant problem was discovered in a very high light flux photocathode test (10^{-2} lumens). Photocathode response was observed to degrade in the center over a long period of time (several hundred hours). The contractor feels that small quantities of adsorbed gases are being released from surfaces due to electron bombardment and that tube outgassing procedures prior to tube processing need to be improved.

PLANS FOR FY'74

The contractor will complete delivery of the two tubes now in test and so complete the contract. No commitment has been received for funding for any further work on this development. Work which should be done to complete this development includes functional, environmental and life testing of the tubes which have yet to be delivered. A new contract should then be negotiated for a second group of tubes to be built for flight qualification purposes.

PUBLICATIONS

1. Goss, W. C., "Image Dissector Development," TM 33-608, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 15, 1973.

GUIDANCE AND CONTROL TECHNOLOGY FOR MARS ROVING VEHICLES NASA RTOP 186-68-55

G. Paine
B. Dobrotin

OBJECTIVE

The objective of this task is to monitor two NASA University Grants which are aimed at developing the technology required for controlling the motion of a roving vehicle on the surface of Mars. This includes developing total vehicle systems to allow assessment of specific techniques developed for suspension, control and guidance. The end objective is to produce designs, specifications and recommendations directly applicable to planetary exploration missions.

PROGRESS-UNIVERSITY GRANTS

Technical monitoring of the progress of Cornell University and Rensselaer Polytechnic Institute (RPI) engineering research grants was maintained throughout the reporting period.

The work performed at Cornell emphazized development of subsystems and their evaluation in a test bed vehicle, while RPI concentrated on subsystem integration and assessment of overall system performance.

The task areas at RPI included vehicle system modeling, vehicle obstacle detection and navigation, gas chromatography, on-board computer evaluation as well as construction of specific subsystems (i. e., vehicle suspension and sensors). Cornell concentrated on building and testing steering control subsystems, soil samplers, tactile and navigation sensors as well as integrating a mini-computer into the navigation system. RPI has relied heavily on computer simulations and analysis, while Cornell has pursued the alternative of developing test hardware for evaluation.

RPI Progress

The generalized vehicle simulation task has been completed. This task developed a mathematical model of the proposed RPI vehicle, subsystem by

subsystem. Constraints were then imposed on the vehicle (i. e., weight, power, etc.) and an optimal design obtained. While the specific solutions obtained depend on the assumptions and constraints used, the techniques developed permit assessment of the effect on the overall system produced by subsystem changes. This will be valuable in assessing future designs.

A parametric study of the on-board computer was started in order to define requirements for the actual vehicle. A model of the vehicle computer was developed and queuing theory was used to generate inputs to the computer. The effects of various computer cycle times were investigated and lower limits on computer capabilities established.

Work was continued in navigation and sensing. Specific tasks include a laser sensor design, sensor error analysis, obstacle detection and path selection. A laser rangefinder using beam modulation (as opposed to the JPL time-of-flight rangefinder) is being investigated. An error analysis of several range-angle measurement configurations has been completed. The objective was to define the effect of sensor errors on slope and obstacle detection. Results found one scheme acceptable - that of elevation, azimuth and range - while indicating the need for a high degree of accuracy in all three measurements. The path selection computer program was refined to give a better index of performance.

A 0. 4-scale model was developed and is under construction. In conjunction with building the actual model, a dynamic analysis is being done. This includes both a two- and three-degree of freedom simulation program. Wheel development has been completed to the point where good correlation between test and analytical results has been obtained.

The gas chromatography analysis has given good results for a mixture of two gases.

Cornell Progress

The vehicle navigation task has concentrated on integrating the DEC PDP-8 into the guidance loop. The special purpose computer was completed and tested. The hardwired algorithm has been transferred to the PDP-8, via an IBM 360-65

simulator. Studies leading to a preliminary design for a radio link between the PDP-8 and the test vehicle have been completed.

Both laser and microwave rangefinders have been built and tested. Laser test results indicate that the laser ranger operates reliably up to 6 ft and can be used to discriminate between dust and a solid object. The microwave rangefinder (radar) has also been tested and gives good results.

A tactile sensor for the vehicle was developed. It consists of a beam which senses the relative motion between the front and center sections of Cornell's test vehicle, via strain gauges. A variety of obstacles was used in testing and gave good results.

A rotary soil sample collector was fabricated and tested with demonstrable results. Conceptual brake designs were developed.

Joint Presentation

A joint RPI-Cornell presentation was held May 10 and 11, 1973 at Cornell. Students from both universities presented summaries from ongoing research.

FUTURE PLANS

During the next reporting period technical monitoring of the university grants will continue. RPI will concentrate its activity in the areas of vehicle design, systems analysis navigation and path selection as well as gas chromatography. Cornell will continue to emphasize subsystem laboratory tests and the design of subsystem vehicle interfaces.

REFERENCES

1. Keba, P. S., and Woodrow, P. T., "Comparison of Two Gas Chromatography Models and Analysis of Binary Data," RPI Technical Report MP-27, Troy, N. Y., July 15, 1972.

2. Frederick, D. K., et al., "Analysis and Design of a Capsule Landing System and Surface Vehicle Control System for Mars Exploration," RPI Technical Report MP-28, Rensselaer Polytechnic Institute, Troy, N. Y., July 1, 1971 - June 30, 1972.

3. Boheim, S. L., and Purdon, W. C., "Path Selection System Simulation and Evaluation for a Martian Roving Vehicle," RPI Technical Report MP-29, Troy, N. Y., Dec. 1972.

4. Frederick, D. K., et al., "Analysis and Design of a Capsule Landing System and Surface Vehicle Control System for Mars Exploration," RPI Technical Report MP-30, Rensselaer Polytechnic Institute, Troy, N. Y., July 1, 1972.

5. Shultz, T., and Livingstone, A., "Laser Rangefinder Obstacle Detector," MRV 72-2, Cornell University, Ithaca, N. Y., June, 1972.

6. Marscher, W., "Tactile Sensor for Mars Roving Vehicle," MRV 72-3, Cornell University, Ithaca, N.Y., June, 1972.

7. Housewright, K., "Heading Detection for an Unmanned Mars Roving Vehicle," MRV 72-4, Cornell University, Ithaca, N. Y., June, 1972.

8. Chen, S., "Soil Sampler for Mars Roving Vehicle," MRV 72-6, Cornell University, Ithaca, N. Y., June, 1972.

9. Housewright, K., "Position Estimation for an Unmanned Mars Roving Vehicle," MRV 72-7, Cornell University, Ithaca, N. Y., June, 1972.

10. Seculic, Z., and Meisenhelder, R., "Steering Control System for an Unmanned Mars Roving Vehicle," MRV 72-8, Cornell University, Ithaca, N. Y., June, 1972.

11. Blackledge, R., and Grover, R., "Computer Assistance for an Unmanned Mars Roving Vehicle," MRV 72-9, Cornell University, Ithaca, N. Y., June, 1972.

12. Marscher, W., et al., "Over-all Systems Coordination for an Unmanned Mars Roving Vehicle," MRV 72-10, Cornell University, Ithaca, N. Y., June, 1972.

PUBLICATIONS

1. Shen, C. N., and Burger, P., "Stochastic Estimates of Gradient from Laser Measurements for an Autonomous Martian Roving Vehicle," Identification and System Parameter Estimation - Proceedings of the 3rd IFAC Symposium, the Hague/Delft, the Netherlands, June 12 - 15, 1973.

SPACECRAFT DATA-SYSTEM TECHNOLOGY FOR OUTER PLANET MISSIONS

NASA RTOP 186-68-56

J. Ashlock
J. Hong
D. Rubin

OBJECTIVE

The goal of this work has been to advance the spacecraft data-system technology of the MJS'77-class spacecraft to provide increased lifetime for missions to the outer planets in 1979 and beyond. The data system is comprised of three distinct subsystems: flight-data subsystem (FDS), central computer subsystem (CCS), and data-storage subsystem (DSS). Each of these subsystems presents a unique problem in terms of increasing its expected lifetime based upon MJS'77 technology.

During mid-year FY'72, the funds for this RTOP were reduced considerably. As a result, all work except for data storage was discontinued. None of the work covered in this RTOP is planned for FY'74.

PROGRESS

Central Computer Subsystem

The purpose of this work is to upgrade the reliability of the MJS'77 CCS to make it suitable for longer duration missions after 1977. By the end of FY'72 the means for achieving the reliability needed for post MJS'77 missions in the Viking Orbiter dual-processor command computer subsystem has been identified. They involve memory module changes and the addition of memory standby redundancy. By that time, however, it had become increasingly evident that subsystem costs had to be held down and that software costs were rivalling hardware costs in magnitude. At the same time it was obvious that the funds available from this RTOP could not support a detailed design and fabrication of an improved redundant-memory CCS breadboard. As a result, the emphasis of this work slipped early in FY'73 to reducing software costs without impairing subsystem reliability. It was felt that the most direct approach to this goal

was to examine the feasibility of a design that directly implements the statements of a special-purpose simplified higher-level language.

Accordingly, a preliminary architecture for the subsystem was considered and a first cut at a software language was attempted. It was felt that an efficient use of hardware could be achieved by providing two levels of microprogramming. The subsystem would contain three memories in all, one for the user program statements, one for a vertical microprogram and one for a horizontal microprogram. The statements encountered in the first would call appropriate subroutines in the second, which would execute primitive operations stored in the third. While this approach limits the maximum operating speed of the subsystem, high speed is not essential and should be sacrificed for reduced hardware and lower cost. The user software statements would contain a string of words specifying a function, the conditions under which the function was to be performed, and the values of any variables required. This approach seemed to simplify all of the high-cost software problems encountered with more conventional designs.

Because of fund reductions during the first half of the year, work on the design was curtailed early in the year and finally halted soon after midyear and little beyond the preliminary investigation was accomplished.

Flight Data Subsystem

The emphasis of this work has been on the continuation of breadboard checkout and testing of the measurement processor subsystem (MPS) which was initially developed for the TOPS data system. Substantial progress was made in FY'72 toward testing the MPS and interfacing it with an IBM 7044 computer which simulates spacecraft interfaces with other subsystems. During FY'73, work relating to debugging of the central computer system (CCS) simulation software was begun, but was not completed because of the funding cut. This computer program was essential to realizing the full capability of the 7044 computer/MPS interface for studying data system problems related to long duration outer planet missions.

Plans for using the MPS/computer to identify and solve the more critical problems caused by cost-constrained missions of the future were also begun. Likewise, these plans were not realized because of the termination of the task.

Data Storage Subsystem

The purpose of this work is to increase the life and reliability of spacecraft data storage subsystems for extended mission application through the development of a fluid-filled magnetic-tape transport mechanism. Development of this hydrofilm transport concept has been pursued by continuing the efforts originally initiated under TOPS.

A reduction of funds precluded the original objective of the design and fabrication of a research breadboard hydrofilm transport by the end of FY'73. However, during FY'73, a mathematical model of the hydrofilm transport was completed and documented, and was used to perform parametric analyses and to guide the detail design of a breadboard. The breadboard design is approximately 90% complete and includes all critical components; documentation is in the form of a drawing package.

Internal fabrication on the hydrostatic motor bearing assemblies at JPL was initiated in February; work is currently in process on this hardware. The motors themselves are already in-house, residuals from TOPS/OPGT. As of January 1973, the fluid head gate specifications were formalized, and the interest and capabilities of potential head manufacturers were evaluated. A purchase order with industry was placed in April; work is nearing completion on this hardware.

The fluid/materials compatibility and aging tests have continued. They have been visually monitored periodically merely to verify integrity of the tests. These tests involve primarily tape samples in fluid samples, although some copper and zinc metal samples are included. The intent is to assess long term compatibility.

This work is not funded for FY'74; consequently, any statement of plans is inappropriate.

PUBLICATIONS

None

OUTER PLANETS ENTRY PROBE HIGH SPEED BRAKING SURVIVAL ANALYSIS

NASA RTOP 186-68-59

F. R. Livingston

OBJECTIVE

The objective of this task is to investigate analytically the technological feasibility of making an atmospheric probe heat shield that will survive entry into the outer planet atmospheres. The task is composed of entry trajectory analysis, flow-field analysis, and dynamic motion analysis. In the entry trajectory analysis, the velocity, altitude, acceleration, and post shock thermodynamic properties are computed for a probe entering a given planet at a prescribed location. The interaction of the shock-layer gas with the ablation layer gas and solid particles is the principal objective of the flow-field analysis. The high ablation rates encountered are expected to have several effects on the probe angular motion and these effects are investigated in 6-degree-of-freedom dynamic motion computer studies.

PROGRESS

Entry trajectory tables and graphs have been compiled for the planets Jupiter, Saturn, Uranus, and Neptune for the nominal and cool model atmospheres for each planet, for ballistic coefficient values of 70, 100, and 140 kg/m^2 for (inertial) entry angles of 90, 40, 30, 20, and 10 deg, and for vehicle nose radii of 0.2, 0.35, 0.7, 1.0, and 1.4 m. These trajectories were calculated using a new "shock-layer + heat transfer" edition of the 2-degree-of-freedom trajectory program, which greatly enhances the usefulness of the data.

Many simplifying assumptions were made, including: continuum aerodynamic conditions, "downwind" equatorial entry, zero lift, no mass loss, constant ballistic coefficient m/C_DA, equilibrium shock-layer thermochemistry, an isothermal, parallel-slab radiative source, a stagnation point convective flux, $Q = \text{const.} [p/R_n]^{1/2} V^2/2$, where R_n is the nose radius, p is the ambient shock layer pressure, and V is the vehicle aerodynamic velocity.

A necessary preliminary to the trajectory calculated was calculation of a matrix of shock-layer thermodynamic and thermochemical data, spanning four decades of ambient pressure, and shock speed in the range 10 to 60 km/sec, for several new H_2/He mixtures, using the JPL Thermochemistry Program. These useful data were published concurrently in two volumes of tables and graphs, pertaining to six gases, with H_2% = 100, 94 ("warm"), 89 ("nominal"), 73 (Saturn "cool"), 68 (Jupiter "cool") and 34 (minor planet "cool").

The trajectories proper have been published in eight volumes, two per planet, as tables and graphs of quantities as a function of time, including height and density of the atmosphere, speed and deceleration of the vehicle, temperature, density, and thickness of the shock-layer, convective and radiative flux and their time-integrals, and also the black-body limiting flux at the shock-layer temperature.

A 6-degree-of-freedom dynamic motion entry program has been developed which can, in a gross sense, account for both the symmetric and asymmetric influences of ablation on the dynamic motion. The program accounts for: mass loss due to ablation, changes in the moments-of-inertia and center-of-gravity position due to symmetric nose recession; and the introduction of an offset center-of-gravity, cross products of inertia, and aerodynamic trim due to asymmetric ablation. Currently the mass loss history, which controls the other stated effects, is inputed in tabular form as a function of time. The information must be obtained from some other source although it is conceivable that in the future an ablation model can be incorporated into the program and the mass loss rates computed. In setting up the actual table it is assumed that 30% of the probe mass is ablated during entry.

A numerical scheme has been developed and flow-charted for inviscid equilibrium flows past circular cones. This is a general scheme which allows for any H_2-He ratio as well as any cone angle in excess of 30°. The scheme then provides the correct boundary condition for the boundary layer with massive ablation in the case of Jovian entries. It also provides a conservative estimate basis for other outer planet entries.

In parallel to the numerical scheme for equilibrium shock layers, analytic solutions have also been developed for frozen shock layers over circular cones.

These analytic solutions allow for any ϵ_s (compression ratio across the shock structure) value which is chemically reasonable within the shock structure. The ϵ_s is unrelated with either γ_∞ or γ_2 in the shock layer. The solutions have been compared with Sim's numerical results (constant γ) and their accuracy is shown to be about 0.003% at $M_\infty = 20$.

A consultant for JPL, Dr. C. J. Chen of the University of Iowa, has used 60°-half-cone angle models (made of dry ice) to simulate ablation layer for Jovian entries. His major conclusion was that in the stagnation region, no catastrophe due to the Taylor instability is likely to occur.

PUBLICATIONS

None

PROPULSION AND PYROTECHNIC TECHNOLOGY FOR OUTER PLANET MISSIONS

NASA RTOP 186-68-62

L.R. Toth
G.A. Yankura

OBJECTIVE

The objective of this work is to determine acceptably inert materials for use in the construction of propulsion system components which will be in contact with earth-storable propellants for long-term missions.

PROGRESS

Storage Test Program

The long-term storage testing of different materials immersed in earth-storable propellants continued without interruption. The environment is temperature-controlled to maintain 43°C (110°F) on a continuous basis throughout the year. Samples consist of stressed, unstressed, welded, and dissimilar metal coupons fabricated primarily from aluminum, corrosion-resistant steel, and titanium alloys. Principal fuels and one oxidizer of the earth-storable class include: hydrazine, hydrazine-hydrazine nitrate mixture, monomethyl hydrazine, and nitrogen tetroxide.

Post-Test Analysis

To date, post-test analyses have been completed on a total of 47 specimen/capsules. The majority of the capsules contained hydrazine. The specimen materials included several CRES 300 series alloys, 6Al-4V titanium, and 6061-T6 aluminum. Specimen types included: slug (simple coupon), bimetal (dissimilar metals in physical contact), lubricant coated, gold plated, and stressed. In some cases the accumulated storage test time was as much as 3 years. The analyses included chemical assay of the propellant and non-volatile residue, determination of the ullage constituents, chemical analysis of surface films, measurement of propellant surface tension and propellant-material wettability, microscopic examination of specimen surfaces, evaluation of material surface ductility, scanning electron microscope imagery of surface

details, and X-ray microprobe analysis of surface coatings. All the above methods of analysis were not applied uniformly, but rather were selected as appropriate for each case. The choice of methods as well as the methods themselves are being refined for subsequent analyses, based on the results of previous analyses.

During this reporting period (FY'73), 12 specimen/capsules were subjected to post-test analysis, according to plan. The selection of the specimen/capsules for analysis was made for the purpose of investigating some anomalies in test behavior, such as relatively rapid pressure rise, as well as to obtain propellant-material compatibility data. Two of the capsules were controls which contained hydrazine only.

In addition to the above, 23 specimen/capsules were subjected to post-test analysis in support of the Mariner Jupiter/Saturn flyby (MJS'77 launch) propulsion subsystem materials selection. This effort was technically relevant to, but not directly supported by, the subject RTOP. Also, selected specimen/capsules were withdrawn from test for evaluation of aging effects of propellant-material exposure on propellant surface tension and wettability. The capsules, 6 with monomethyl hydrazine and 6 with nitrogen tetroxide, had accumulated up to 33 months in storage test, a duration longer than the scheduled nominal mission.

As a result of visual observations on other specimen/capsules in test, which indicated the failure of propellants to completely wet specimens coated with a lubricant of the same type as that being employed in components of the Viking Orbiter propulsion subsystem, the flight project undertook tests to measure quantitatively this effect in order to establish the tolerable quantity limits for the flight systems.

Specific Findings

The exposure to hydrazine of the classes of materials tested results in an adherent oxide film (less then 1μ thick) on the surfaces exposed to the vapor. The surfaces exposed to the liquid remain free of film. Our only concern with this film formation is with respect to recycling systems in multiple reuse applications where the film might cover surface voids which could then

trap propellant, referee fluid, cleaning fluid, or contaminants, in the various stages of the cycle. The film appears also to be subject to shrinkage cracking and flaking under drying conditions.

The examination by scanning electron microscopy of reference specimens which represent the prepropellant exposure material condition, revealed that the commonly used process for passivating stainless steels results in micro-pits which may serve to accelerate corrosion at these sites. In any event, they can be expected to increase the difficulty of cleaning components. In the control capsules which contained only hydrazine, the pressure rise after 3 years was on the order of 1 psi.

The presence of chloride and fluoride ions, the result in this case of residual freon cleaning agent reacting with the hydrazine, was found to accelerate hydrazine decomposition. For example, two specimen/capsules, both CRES 302 coated with Krytox 240AC in hydrazine, experienced 0.2% and 0.1% hydrazine decomposition in 59 and 305 days, respectively. The chloride ion contents were 150 ppm (by weight in the hydrazine) and 36 ppm, respectively. The corresponding fluoride ion contents were 100 and 19 ppm.

It was found that a gold plating can be lifted by corrosion of a stainless steel substrate where it is exposed to hydrazine by minute breaks in the plating because of microscopic surface imperfections in the substrate. The gold plating itself was found to be unaffected by exposure to hydrazine.

The presence of Krytox lubricant appears to have no effect on material corrosion or hydrazine decomposition, and is itself not affected by hydrazine.

Another observation was that gold plating, Inconel X, and nickel all enhance the reaction which produces hydrogen from hydrazine decomposition, relative to the reaction which produces ammonia.

General Conclusions

Hydrazine decomposition rates of less than 0.10 of 1% per year should be attainable in systems using the metal alloys: 6Al-4V titanium, 6061-T6 aluminum, CRES 300 series, and CRES 416.

PLANS FOR FY'74

The storage testing of specimen/capsules remaining in test will be continued and additional post-test analysis of specimen/capsules will be conducted to provide additional real-time propellant-material compatibility data and to further the understanding of corrosion mechanisms. In addition to work under the RTOP, it is anticipated that support of post-test analysis will again be provided by flight projects such as MJS.

PUBLICATIONS

The following publication was inadvertently omitted from last year's annual report and is included here for completeness:

1. Razouk, R., "Surface Tension of Propellants," QTR, Vol. 2, No. 1, Jet Propulsion Laboratory, Pasadena, Calif., Apr. 1972.

ENVIRONMENTAL REQUIREMENTS AND SIMULATION FOR OUTER PLANET MISSIONS

NASA RTOP 186-68-69

A.J. Beck
N. Divine
J.S. Zmuidzinas

OBJECTIVE

The general objective of this work is to develop the technology required to extend the capability of Mariner-type spacecraft for long duration missions to the outer planets and the associated environments. Three subtasks are included:

(1) Jupiter radiation belt studies leading to improvements to the upper limit model of Jupiter's trapped radiation
(2) Development of radiation test technology
(3) Investigation of life limiting elements/characteristics of Mariner subsystems

However, because of a reprogramming of funds in the 186-Program, the last two subtasks were deleted from consideration early in the program and the first task was severly curtailed primarily to the work performed under contract with the University of California at Los Angeles. Consequently, the results reported here are for the first task and the remaining two are not discussed further.

The Jupiter radiation belt subtask, arising largely from the severe degradation anticipated for electronic and other components from exposure to protons described by current upper limit models of the trapped radiation, is to develop the most thorough theoretical analysis of the charged particle populations possible prior to Pioneer encounter, using a research study contract.

PROGRESS

A limited analysis of diffusion in Jupiter's magnetosphere has been completed by S.A. Jacques and L. Davis, Jr., of Caltech, supported by this RTOP. Models for diffusing energetic electrons were formulated including losses to synchrotron radiation and absorption by a satellite. Of the three diffusion

mechanisms considered, only one driven by ionospheric winds is capable of both providing the electron population inferred from radio observations of Jupiter and a hazardous, large proton population.

Computer-generated profiles of electron and proton distributions have been obtained including both electronic- and magnetic-field fluctuations as the diffusion mechanisms, satellite sweeping, and the dipole tilt for both electron and protons, including as well the ion-cyclotron instability for the protons. Resultant electron fluxes are generally larger, and proton fluxes smaller, than in the corresponding upper limit models previously developed (Jupiter Radiation Belt Workshop, JPL TM 33-543).

An informal, comparative review, including the above work and that completed or in progress elsewhere, of Jupiter radiation belt analyses was completed. The status of the Jupiter radiation environment formed a major portion of a Laboratory Research Conference at JPL, January 5, 1973.

Research under the Study Contract (No. 953490) supported by this RTOP has been completed by Drs. Coroniti, Thorne, and Kennel at UCLA. Applying their thorough analyses of wind-driven, fluctuating electric field diffusion; ion-cyclotron, whistler, and quasi-electrostatic mode plasma wave instabilities; satellite absorption including the dipole tilt; and synchrotron energy losses (for the electrons) they have computed models for the distributions of electrons and protons in position, energy, and pitch-angle, using as sources the solar wind and solar particle events. The electron results, considerably more severe than prior models except in the inner zone, reproduce the observed radio emissions well; the application of the parameter values necessary for the electron results yields proton fluxes only modestly more severe than previous models. In addition to interim progress reports, the draft of a final report on this research has been completed, and the final report and published journal articles describing this work will become available early in FY'74. These will fulfill the objective of deriving thorough theoretical models for charged particle populations near Jupiter.

PUBLICATIONS

1. Coroniti, F.V., Kennel, C.F., and Thorne, R.M., "A Model for Jovian Electron and Proton Fluxes," AGU Transactions EOS, Vol. 54, No. 4, 446, 1973.

2. Jacques, S.A., and Davis, L., Jr., "Diffusion Models for Jupiter's Radiation Belt," California Institute of Technology Technical Report, 34 pp., 1972.

COMPUTER ANIMATED MISSION DESCRIPTION FILMS

NASA RTOP 186-68-70

P.H. Roberts
W.W. Yip

OBJECTIVE

The objective of this RTOP has been to aid NASA in describing future planetary missions by effectively utilizing computer animated films. Such films have been valuable in the past in facilitating trajectory selection and in illustrating mission concepts to both scientific and nontechnical bodies.

PROGRESS

Although originally planned as a year-long activity, the RTOP was terminated at the end of the first quarter of FY'73. From June - September 1972 two films were made, illustrating Venus Pioneer Missions and similar to those previously made for the Outer Planets Missions.

Using the trajectory data available from NASA Ames Research Center (ARC), scenes were generated which effectively illustrate mission profiles and other pertinent features for a 1976/77 Multiple Probe Mission and a 1978 Orbiter Mission.

The 1976/77 Multiple Probe Mission would be launched in January 1977, releasing from the bus four probes targeted to various locations on Venus. One of these, the large probe, would be released 15 days before bus impact and the three smaller probes one day later.

The 1978 Orbiter Mission would be launched in May 1978. The spacecraft will be inserted into a 24-hour elliptical orbit about Venus.

The first film "Pioneer Venus Missions" depicts both missions; the second, "Pioneer Venus Orbiter Mission," is basically the latter half of the first film. Prints of the preliminary and final versions of both films have been delivered to NASA-SL and to the ARC-Pioneer Venus Project Office.

Brief descriptions of the films follow:

1. Pioneer Venus Missions Computer Animation (Silent - 10 min.)

   The film depicts the 1976/77 Multiple Probes Mission and the 1978 Orbiter Mission.

   The movie consists of eight scenes with four devoted to each mission. The following are summary statements of the various scenes. (1) Shows the heliocentric flight of the spacecraft from earth to Venus; (2) earth view of the trajectories of the spacecraft and the probes approaching Venus; (3) shows the trajectories of the probes approaching Venus as seen from the bus; (4) Large Probe Venus atmospheric entry and descent; (5) shows the helicentric earth to Venus trajectory of the Orbiter Mission; (6) shows the spacecraft approach trajectory, orbit insertion and two revolutions; (7) this is a view from earth of the spacecraft orbit for one sideral year; (8) shows the view from the spacecraft for one orbit.

2. Pioneer Venus Orbiter Mission Computer Animation (Silent - 5 min.)

   The film depicts the 1978 Orbiter Mission.

   The movie consists of four scenes. Scene 1 shows the heliocentric trajectory and begins at 38 days before launch with the viewer situated at 3 AU above the ecliptic plane. As time progresses the viewer moves to 2.5 AU and swings down near the ecliptic plane. The viewer remains stationary briefly as the spacecraft is launched and then zooms in as the flight progresses. Scene 2 shows the view of the incoming trajectory followed by the orbit insertion and the first revolution. The second revolution begins with the view from the sun to the earth. The viewer then progresses through 270^{o} in longitude. Scene 3 is a view from the earth of the spacecraft orbit for one sidereal year. Scene 4 initially puts the viewer on the spacecraft looking at Venus for one orbit beginning and ending at apoapsis. The second part puts the viewer some distance above the spacecraft, begins one hour before periapsis and ends one hour after periapsis.

More detailed film descriptions may be obtained from the Advanced Projects Group, JPL Mission Analysis Division.

PUBLICATIONS

None

ELECTRONIC PARTS AND PACKAGING FOR OUTER PLANET MISSIONS NASA RTOP 186-70-51

T.R. Gavin
J.O. Lonborg
W.S. Read
R. Shima
R.J. Wahlgren

OBJECTIVE

The long-range objective of this work was to develop the necessary electronic parts and packaging technology which would enable upgrading of the MJS spacecraft for 8- to 10-year outer planet missions. Specific FY'73 objectives included: support of the microminiature receiver development task (186-68-53); development of high resistance value, beam-leaded chip resistors; establishment of a metalization capability suitable for the fabrication of long-life microwave hybrid circuits; development of low-cost electronic packaging techniques; and investigation of radiation hardening techniques for electronic devices.

PROGRESS

In response to NASA cost constraints, this RTOP was reprogrammed in December, 1972 and many of the originally planned activities had to be curtailed. The RTOP was terminated at the end of FY'73. Progress toward accomplishment of the above objectives is reported in the following sections.

Microminiature Receiver Development Support

The microminiature receiver development task (186-68-53) was pursued by a combination of in-house and contracted efforts. One of the principal items supported by this RTOP was the overall packaging of the receiver. Electronic packaging personnel participated in the design review. When it became evident that there were serious deficiencies in the receiver packaging design, an alternate design was generated under this RTOP. As part of this, a hybrid circuit carrier consisting of a "picture frame" (with feed-through terminals)

and two covers was designed. Prototypes were furnished to the Telecommunications Division. Other packaging support items included beam-lead bonding and the development of mounting methods for hybrid circuit substrates. One of the results of the latter task was the selection of titanium as having the best combination of properties for the hybrid carrier base.

A reasonably satisfactory method for fabricating test holders for beam-leaded chips was developed and documented. Prototype devices were supplied for use in the receiver development. A thermal model of the receiver was developed and used in temperature control studies. The microminiature receiver development support task was terminated in March 1973.

Beam-Leaded Chip Resistor Development

Contract 953474 was let to Airco Speer Electronics June 20, 1972, for the development of high value, beam-leaded chip resistors. This was modified July 5, 1972, to provide for the development of a beam-leaded binary resistor array for use in the microminiature transponder. Subsequent reprogramming of the RTOP required reduction of the scope of the contract.

The development of the binary resistor array was completed, parts were received, and additional parts have been procured and are being qualified on other funds. Work on the high resistivity films was about 50% complete when the contract was terminated, and useful devices were obtained. Testing of these parts has been initiated, using other funds, to ascertain their reliability.

This effort provided the advanced transponder with a resistor critical to the circuit design. All design goals were met. A beam-leaded chip resistor was fabricated using a film material with a resistivity approximately five times greater than present state of the art. All goals defined by the reduced scope development contract were met.

Thin-Film Metalization Technology

The objective of this task was to establish a single metalization structure compatible with thermocompression bonding and with beam-lead processing, which would withstand processing temperatures up to 800°C, and have good long term stability.

Ti/Mo/Au metalization on Al_2O_3 substrate material was selected as the most favorable structure. The Mo/Au is stable but, because of the instability of the Mo/Al_2O_3 structure, Ti is introduced to provide good adhesion and act as a "getter."

A tri-metal sequential sputtering system[1] was designed, developed, and constructed to sputter Ti/Mo/Au sequentially, without interruptions between layers. Films produced with this equipment were analyzed by means of backscattering and were evaluated mechanically. To produce high quality films meeting design objectives, the following are necessary:

(1) The Al_2O_3 substrate grain size must be 10 μin. or less, and the surface finish must be 20 μin. or better.
(2) Sequential sputtering is necessary to control the interface between metalization layers.
(3) Metalization thicknesses should be: Ti, ~500 Å; Mo, ~500 Å; and Au, 2000 Å minimum.
(4) Annealing in vacuum or argon up to 600°C for 10 min does not deteriorate the metalization structure. Above 650°C Ti forms a complex reaction layer with Al_2O_3; therefore the annealing time must be reduced to 3 min.

Backscattering analyses have been used for estimating life stability. Samples prepared in vacuum at 800°C for 10 min showed complete disappearance of Ti, as predicted in (4) above.

Using masks fabricated by Marshall Space Flight Center (MSFC) to JPL designs, fine lines 2μ wide with 2μ spacing were etched on specially metalized substrates. These efforts demonstrated JPL's in-house capability for producing high resolution filters and transducers, as required for next-generation microwave circuitry. Further refinement in technique is still needed to eliminate defects in pattern details. Ion etching has also been investigated as an alternate technique, and shows promise for obtaining even higher pattern resolution.

---

[1] New Technology item, JPL Case No. 3020.

Low-Cost Electronic Packaging

The objective of this task was to develop techniques for using less expensive extrusions and sheet metal construction in place of machined parts for chassis and subchassis. With the help of funding from other sources, obtained after the reprogramming of this RTOP, the planned objectives were achieved, with the exception of the final report. Means for producing the report are being sought.

Two concepts were developed. One is a relatively small departure from current practice, in that it directly replaces the present Mariner C-type integral shear panel chassis, which is machined from a forging, with a riveted assembly of sheet metal parts and extrusions. The new low-cost chassis was designed, documented, and analyzed structurally and thermally. Vibration testing of the prototype chassis confirmed that the dynamic characteristics are not significantly different from those of the machined chassis. This chassis design has been adopted for use by the MJS'77 project, and will yield a savings of $15K per spacecraft, or a total of $54K for the project.

The other concept involves redesign of the electronic compartment. The new compartment resembles the present octagon, but the subassembly chassis are trapezoidal and are attached to shear plates around both interior and exterior faces of the octagon, thus improving structural integrity. The subassembly chassis is a honeycomb-like composite structure. This technique can be selectively applied, permitting use of existing Mariner and Viking designs and hardware, where desired. The concept has not been fully developed, nor have all the means for achieving cost savings been explored. However, enough dummy subassemblies were fabricated to fill one equipment bay. Figure 1 shows these installed in a mock-up bay. An electronic assembly was created by attaching shear plates to these dummy subassemblies. This was subjected to vibration testing, mounted in a modified VO'75 vibration test fixture. Results of this testing indicate that dynamic performance in two axes is equal, or somewhat superior, to that of standard Mariner and Viking assemblies. In the third axis, the natural frequency was below the design requirement, indicating the need to improve the attachment between the subassembly chassis and the inner shear plate. No difficulty is foreseen in correcting this.

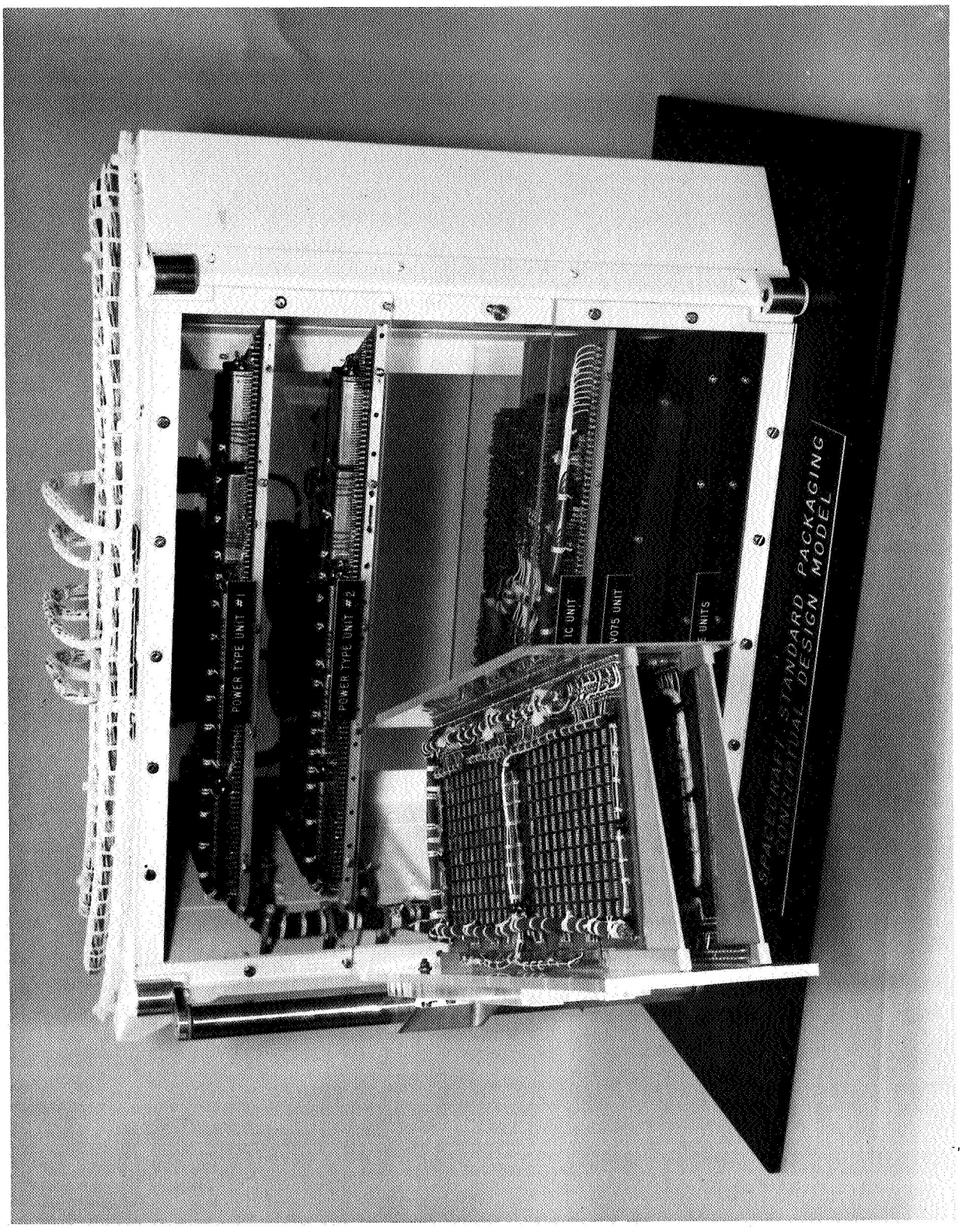


Figure 1. Spacecraft Standard Packaging Conceptual Design Model

Principally because this concept is presently not fully developed and qualified, MJS'77 does not now plan to use it. However, interest has been shown in it, because of its obvious advantages. It would still be possible to implement parts of the concept on certain subsystems if adequate funding were available to complete the development in a timely manner.

Two alternate proposals based on this concept have been submitted to NASA Headquarters for possible funding in FY'74. "Electronic Packaging for Planetary Missions" would complete the development and qualification necessary to fully implement this concept on an MJU'79 spacecraft and subsequent planetary spacecraft. The estimated savings to an MJU'79 project through implementation of all the packaging technology proposed to be developed is $1.5M, and additional savings would be available to other planetary projects. "Standard Electronic Equipment Packaging System" presents a slightly different approach to completing the development and qualification of a packaging system based on this concept. The idea is to create a somewhat flexible standard, with predictable performance, which would be broadly applicable to NASA planetary and interplanetary projects. At present, it is not known whether either of these proposed RTOPs will be funded.

Radiation Hardness Assurance

The objective of this task was to develop appropriate techniques for spacecraft component and circuit design hardening for both RTG and Planetary Trapped Radiation. This was to be accomplished by analyzing typical subsystem designs which were candidates for future Outer Planet Missions. The analysis rules, contractor statement of work, and preliminary parts information were provided. Support by this RTOP was then terminated, due to reprogramming, but the work was picked up by the MJS'77 Project. Two subsystem designs (MVM'73 TV and VO'75 CCS) have been analyzed thus far, and analysis of three others is in progress.

PUBLICATIONS

1. "Subsystem Radiation Sensitivity Study MVM'73 TV," General Electric Space Division Report No. 73SD4235, May 11, 1973.

2. "Subsystem Radiation Sensitivity Study VO'75 CCS," General Electric Space Division Report No. 73SD4234, May 11, 1973.

STERILIZATION TECHNIQUES
NASA RTOP 193-58-61

OBJECTIVE

The objectives of this RTOP are to perform analytical and experimental studies in the area of planetary quarantine aimed at the development of probability numbers for potential contamination events relevant to future missions. Specifically, these studies include: (1) an analysis of planetary quarantine constraints for Jupiter-Saturn flyby missions, encounter of Saturn's rings, and atmospheric probes; and (2) studies to determine the effect of the natural space environment on the survival of microorganisms.

The studies are being conducted to identify planetary quarantine constraints for future missions in order that procedures and methodologies can be developed by which JPL and other flight programs can reliably satisfy these requirements. Existing JPL facilities are used to conduct these studies and a multidisciplined team is employed to perform analyses for advanced missions. This team includes support for the definition of the natural space environmental parameters, spacecraft flight environments, mission analysis and microbiology.

PROGRESS

Strategies for Satellite Encounter

To calculate the probability of impacting a satellite of Jupiter or Saturn by a spacecraft during an outer planet mission required the formulation of new mathematical procedures which: (1) determined the area in the planet aimplane that would result in trajectories that impact the satellite (planned encounter); and (2) provided a technique for numerically integrating the navigation error function over the impact area in order to obtain impact probabilities. A computer program was developed and the newly developed software was applied to typical outer planet close satellite encounter missions involving Titan (Saturn) and Io (Jupiter). From the analyses, implications of satellite quarantine constraints on these missions were derived. The results show significant differences between planetary and satellite quarantine implications on multiple outer planet missions. For example, trajectory correction

maneuvers that resulted in a possible satellite quarantine violation were different from those violating planetary quarantine. Also, the results indicate that the probability of impact due to errors in trajectory correction maneuvers is a strong function of the spacecraft aim-point relative to the satellite, even for constant distances of closest approach.

Jupiter Entry Analysis

This study has applied classical aerothermophysics techniques to determine the thermal responses of selected components of a typical Jupiter flyby spacecraft as well as ejecta and disintegration debris as they pass through the free-molecular flow regime and early continuum. Analyses for the entire spacecraft have shown that the thermal insulation blankets and the antenna are completely disintegrated by the early continuum. Large components, such as the spacecraft main support structure with the attached electronics and the science platform, will not receive sufficient heating in the free-molecular regime to cause major disintegration. However, complete disintegration is expected to occur in the continuum regime; analyses are being performed to determine the thermal response of these structures in the continuum. The analysis of spherical plastic particles indicates the existence of "survival corridors" which indicate that small diameter particles are the most likely to survive entry heating.

The Mariner Jupiter/Saturn spacecraft science platform was selected for thermal response analysis. An analysis was completed for the ultraviolet spectrometer (UVS) plastic lens cap. The UVS which contains a substantial number of plastic and non-plastic components separated by voids is representative of a complex isolated unit. A full size sketch identifying the location and configuration of the UVS components was constructed from an engineering drawing. Decomposition tests were conducted on the plastics and results analyzed; chemical composition and material properties were determined. Particle analyses indicate that for all model atmospheres temperature increases resulting from entry heating depend on particle size and entry angle.

Effect of Planetary Trapped Radiation Belt on Microorganisms

A spacecraft bacterial subpopulation (nine sporeforming and three non-sporeforming isolates) plus two comparative organisms, Staphylococcus epidermidis and Bacillus subtilis var. niger, were exposed to 2 MeV protons and 2 and 0.6 MeV electrons at different exposures and exposure rates with simultaneous subjection to a vacuum of 10^{-6} torr at 20 and -20 °C.

Analysis of the 2-MeV proton data indicates that approximately 18, 10, and 4 percent of the spore populations survived fluences of 5×10^{11}, 1×10^{12} and 5×10^{12} protons cm^{-2}, respectively. The non-sporeforming isolates were generally more sensitive, with survival fractions 2 to 3 orders of magnitude lower. Both types of populations were significantly less sensitive to the flux at 4×10^{10} protons cm^{-2} s^{-1} than the 10^{8} and 10^{9} exposures at a constant fluence of 10^{12} protons cm^{-2}.

A preliminary analysis of the complete 2-MeV electron matrix shows that the radioresistance of spores is lowest at a flux of 10^{10} e cm^{-2} s^{-1}, followed by 10^{11} and 10^{9}. This result is in agreement with the previously reported result at one dose level, 300 krad. The radioresistance of the non-sporeformers is lowest at a flux of 10^{11} e cm^{-2} s^{-1}, in agreement with the previous 300 krad data. However, the 10^{10} e cm^{-2} s^{-1} data indicates a greater radioresistance than the 10^{9} data. An analysis of variance of the complete test matrix inclusive of 2, 12 and 25 MeV electrons is under way.

A test matrix for 0.6 MeV electrons has been started. The raw data indicates that on an equal dose and dose rate basis the radioresistance of the microbial populations is slightly higher at this energy than at 2 MeV.

Effect of Solar Wind Radiation on Microorganisms

Due to reprogramming of resources, the level of effort on this task had to be reduced. The study will be conducted in-house so that the schedule can be adjusted in accordance with resources available. An experimental setup has been designed and preliminary tests are under way to determine the effect of 100-eV electrons on baterial isolates.

Effect of Space Vacuum on Microorganisms

A microbial subpopulation from MM'71 spacecraft was exposed to simulated space vacuum of 10^{-8} to 10^{-9} torr at -40, 25, 40, and 55 °C for periods of 7, 14, 28, 56, and 187 days.

Analyses of data show a lethal response dependency upon temperature, duration of exposure, and isolate. Considering the longest exposure, 187 days, survival fractions of spacecraft isolate spores were 1.77, 0.67, 0.04, and 0.002 for respective exposure temperatures of -40, 25, 40, and 55 °C while the survival fractions of spacecraft isolate nonsporeformers were 0.33, 0.07, 0.02, and 0.003 for the same exposure temperatures, respectively.

Probability of Growth in Planetary Atmospheres and Satellites

Environmental parameters affecting growth of bacteria (e.g. moisture, temperature, pH, chemical composition) were compared with current atmoshperic models for Jupiter and Saturn, and with the available physical data for their satellites. A zone of highest probability of growth (P_g) previously reported for Jupiter (i.e. between 10 and 100 at) was also identified for Saturn. However, the 20 or more satellites of Jupiter and Saturn differ greatly from their planets. Based on a P_g analysis established for Jupiter, four Jupiter satellites ranging from "moonlike" to "icelike" in physical and chemical composition and a satellite of Saturn (Titan) having a definite atmosphere, appear to be of biological interest. The other satellites of Jupiter and Saturn probably cannot support growth owing to their extremely low temperatures. Surface characterization of the Jovian satellites has been difficult; only their sizes and average surface temperatures have been determined. Significant P_g values for the satellites must be based, therefore, on the assumption that surface regions are not uniformly cold as would appear from the relatively crude data available, or that microorganisms can penetrate the relatively hostile surface to survive and grow in warmer regions of these bodies.

PLANS FOR FY'74

(1) Complete the Jovian atmospheric entry analysis including indication of parts most likely to contain surviving microorganisms

(2) Initiate atmospheric entry heating analysis for Saturn in order to identify spacecraft components with a potential for containing surviving microorganisms

(3) Complete the satellite quarantine strategies analyses

(4) Investigate effect of protons at higher energies on spacecraft microbial isolates

(5) Complete tests on 0.6-MeV electrons and extend study to lower energies

(6) Initiate an investigation of the amounts and types of secondary radiation resulting from the interaction of primary radiation with spacecraft surfaces

(7) Analyze and model the radiosensitivity of the microbial populations

(8) Complete the preliminary work with 100-eV electrons

(9) Conduct a low energy electron study at three energies, exposures, and dose rates

(10) Design or locate an existing facility to conduct an analogous test program for low energy protons

(11) Prepare open literature report on effect of space vacuum

(12) Perform additional space vacuum studies with naturally occurring, noncultured spacecraft organisms

(13) Prepare for the open literature a paper on the probability of growth study

(14) Develop a simulator for exposure of microorganisms to the solar electromagnetic spectrum under conditions of deep space vacuum at representative spacecraft temperatures

PUBLICATIONS

1. Hoffman, A.R., Stavro, W., and Gonzalez, C., "Quarantine Constraints as Applied to Satellites," paper presented at the 16th Plenary Meeting of COSPAR, Constance, Federal Republic of Germany, May 23-June 6, 1973.

2. Hoffman, A.R., Gonzalez, C.G., Jaworski, W., and McRonald, A.D., "Spacecraft Microbial Burden Reduction Due to Atmospheric Entry Heating-Jupiter," paper presented at the 16th Plenary Meeting of COSPAR, Constance, Federal Republic of Germany, May 23-June 6, 1973.

3. Gonzalez, C., and Stavro, W., "The Significance of Outer Planet Satellite Quarantine Constraints on Aim-Point Selection," Proceedings of AIAA/AGU Space Science Conference: Exploration of the Outer Solar System, Denver, Co., July 10-12, 1973.

4. Taylor, D.M., Hagen, C.A., Renninger, G.M., Simko, G.J., Smith, C.D., and Yelinek, J.A., "Survival of Bacterial Isolates Exposed to Simulated Jovian Trapped Radiation Belt Electrons and Solar Wind Protons," W. Vishniac, ed., in Life Sciences and Space Research, Vol. XI, pp. 33-39, Akademie-Verlag, Berlin, Germany, 1973.

MICROBIAL ANALYSIS
NASA RTOP 193-58-62

OBJECTIVES

The objectives of this RTOP are to develop analytical tools and perform experimental studies in order to estimate the recontamination hazard for spacecraft hardware. All physically significant parameters and processes are to be analytically modeled and, where possible, experimentally verified to obtain a reasonable level of confidence in the results.

A combined discipline approach will be used to: (1) perform tests in existing JPL facilities in order to obtain data for the verification of the analytical models; (2) perform analytical and empirical correlation studies; and (3) perform mission strategy analyses to assess their impact on recontamination phenomena.

PROGRESS

Post Launch Recontamination Studies

During this reporting period, the effort has continued in the spaceflight phase where the important environments for particle release are pyro events and meteoroid impacts. The computer codes for the approximate analytical solutions for meteoroid impact have been completed and some numerical results obtained. Codes for the new more exact analytical solutions are still in development. Analyses and computer codes for the electric field at and near an illuminated plate in the solar wind plasma and for the charging rates and equilibrium potential of particles have been completed. Numerical results have been obtained. The preliminary trajectory code has been exercised with the electric field and the particle charging subroutines in several simple physical configurations. The results indicate that the initial velocity of a released grain (particle) is a critical parameter.

The data from the present particle release experiment have been analyzed. These results for glass beads in vacuum display a significant dependence on ambient loading conditions. A comparison with the Langley Research Center

results for a "clearing radius" experiment provides possible insight into the input parameters for the meteoroid impact codes. The need for simplifying the counting procedure of released particles so that materials other than glass may be used and the new need for velocity information have led to a feasibility study of employing an acoustic emission detection system. This study has provided encouraging results. Plans for a new particle release experiment are being developed.

PLANS FOR FY'74

(1) The three-dimensional electric field and a final trajectory routine will be integrated with the geometry code.
(2) An improved analysis of the electric field and the particle charging in the shade will be developed.
(3) Particle release experiments to determine release velocities and fractions removed with more realistic samples by the use of acoustic emission detection will be performed.

PUBLICATIONS

1. Barengoltz, J. and Bauerle, C., "The Electric Field in the Vicinity of a Photo-emitting Plate in a Plasma," QTR, Vol. 3, No. 1, Jet Propulsion Laboratory, Pasadena, Calif., 1973.

CONTAMINATION CONTROL
NASA RTOP 193-58-63

OBJECTIVE

The objective of this RTOP is to develop methodologies and procedures for the reduction and probability estimation of microbial burden on an assembled spacecraft at the time of encapsulation or terminal sterilization or during flight. The plan contains five activities: (1) the development of guidelines for the design and use of more efficient mechanical cleaning tools; (2) the evaluation of hydrogen peroxide as a bactericidal agent for use on spacecraft hardware; (3) the development of plasma sterilization technology which can be applied to problem areas in the decontamination of spacecraft hardware; (4) the development of mathematical tools and methods for estimation of probability parameters; and (5) the support of the NASA Headquarters Planetary Quaratine Officer as directed.

PROGRESS

Physical Removal of Spacecraft Microbial Burden

A test apparatus to simulate steady state blow-vacuum cleaning has been designed and fabricated. Blow-vacuum cleaning tests with 5- to 10-μm diameter glass beads seeded on optical glass have been completed. Results show that the removal efficiency of a vacuum cleaning device operating from a conventional facility vacuum system can be greatly improved by blowing locally under a slant angle onto the surface where the velocity of main vacuum flow is maximum. For dry adhesion almost all of the test particulates could be removed at pressures on the order of 10 to 30 psig across the blow nozzle. For oily and moist surfaces, however, 40 to 80 psig pressures and repeated sweeping were necessary for efficient removal.

Verification of USSR Hydrogen Peroxide Decontamination Data

Survivor curves were generated for 7 spores and 3 nonsporeformers exposed to concentrations of 3, 10 and 15% hydrogen peroxide. Challenge cultures of nonsporeformers were rendered nonviable after 10 min exposure

to 3 percent peroxide while it took approximately 60 min to effect a one-log reduction in the mean spore population. Extinction of visible spores in 10 and 15 percent solutions was observed after approximately 30 min exposure. Some hydrogen perioxide induced spore activation was noted.

Evaluation of Plasma Cleaning and Decontamination Techniques

An 18-mo contract was awarded to The Boeing Co. (May 15, 1973) to develop plasma sterilization technology for spacecraft applications, and to generate preliminary design criteria for sterilizers. The study effort is divided into two major areas: (1) to determine the effective sterilizing ranges of different gases as a function of power, gas flow rate, and chamber pressure; and (2) to determine penetration characteristics and material compatibility of plasma as well as to develop design criteria for plasma sterilizers.

Probability Estimation Methods and Analysis

An extensive critique of probability estimation methods and analytical models used by the planetary quarantine was performed. It was concluded that the methods and models are basically sound. However, some of these methods and models can be made more mathematically rigorous by restructuring their formulation. An approach for analyzing the vacuum temperature data, based on a log normal model and a least squares fit, was developed.

A final report describing the work through January 1973, when funds were terminated, has been published in the JPL Planetary Quarantine Semiannual Review, JPL Document 900-608.

Planetary Quarantine Operations

During the past year, a full-time resident professional continued to provide day-to-day support to the NASA Planetary Quarantine Officer until reassignment in February 1973. Temporary support was provided during the May-June 1973 period.

This task also covers general administrative and programmatic support of JPL planetary quarantine research program as well as the preparation of program planning material for the Planetary Quarantine Officer.

PLANS FOR FY'74

(1) Complete the pulse flow testing program of the physical removal of microbial burden task

(2) Initiate materials selection and design of improved cleaning brushes

(3) Continue evaluation of chemicals for spacecraft microbial decontamination

(4) Continue the development of plasma sterilization technology and generate preliminary design criteria for sterilizers

PUBLICATIONS

None